

2008-01-01

Noise Abatement and Night Deliveries

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NOISE ABATEMENT AND NIGHT DELIVERIES

Hugh Finlay

Dublin Institute of Technology

M.Phil

2008

NOISE ABATEMENT AND NIGHT DELIVERIES

HUGH FINLAY

A Dissertation presented to the Department of Transport Engineering

Dublin Institute of Technology

October 2008

Supervisors: Dr. Anthony Betts, Mr. Tom Corrigan and Dr. James Walsh

DECLARATION

I certify that this thesis which I now submit for examination for the award of Master of Philosophy, is entirely my own work and has not been taken from the work of others save and to the extent that such work has been cited in and acknowledged in the text of my work.

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Mr. Hugh Finlay

Date

ACKNOWLEDGEMENTS

A great debt of gratitude is owed to my colleagues of DIT for their kind support and encouragement.

Dr. Tony Betts was diligent with his supervision and was always generous with his encouragement and time. Mr. Tom Corrigan facilitated and supported me in every way and ensured that the resources of his department were at my disposal. Dr. James Walsh kindly advised on the proper conduct of the research and on the standards to be expected.

As team members of the Innovation Partnership of which this thesis is a part, Roisin Byrne and John Grimes contributed significantly to the conduct of the experiments and field trials. Roisin created a stimulating and creative work environment and ensured that all the elements of the Innovation Partnership were delivered effectively. John helped me to translate the conceptual experiments into practical reality and his assistance in interpreting and presenting the substantial data bases was greatly valued. James Ryan conducted acoustic damping experiments as part of his final year degree project, which was relevant to this research.

Deserving special mention are Tim Harding who fabricated the test rigs in his workshop and Gary Duffy of Bruel and Kjaer who advised on the methodology and procedures. I also wish to acknowledge Niall Stobie of CREST/DIT and Pat Layde of General Paints Ltd. who formulated the acoustic coating. I particularly wish to thank Brian McManus head of the Traffic Noise and Air Quality Unit, Dublin City Council for his invaluable guidance and for making his noise monitoring equipment available.

In all of this endeavour the encouragement and patience of my dear wife Clare was greatly valued.

ABSTRACT

The hypothesis is tested that –

Acoustic materials are available or can be developed and applied to Heavy Goods Vehicles and ancillaries, which effectively and economically abate the noise caused by night deliveries

The MPhil is a part of a wider innovation research partnership that aimed to develop sustainable solutions for the growing trend to night deliveries in Dublin city centre.

The methodology involves; a review of international best practice for urban traffic noise abatement: a social and commercial justification for developing low noise products and procedures: field trials of kerb-side deliveries to city centre shops to identify the “peak” noise events and their associated signature frequencies: an identification of the HGV components and ancillaries to which noise attenuation solutions might best be applied: the selection, matching and pre-screening of suitable acoustic coatings for application to HGV trailer bodies and tail lifts: the development and evaluation of a hush-kit for easy retro-fitting to steel roll-cages. Laboratory and field experiments and special test equipment were designed to support and to validate the research.

The research concentrates on bringing forward two sets of solutions (a) the application of an acoustic coating to the HGV trailer unit and tail-lift platform and (b) the development of a hush-kit for the steel roll-cages. The focus is on attenuating the identifiable peak impact noises by matching these with a coating and materials that can dampen the characteristic high frequency sounds. Recommendations are made for further research to optimise the performance of the prototypes developed.

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CHAPTER 1. BACKGROUND AND JUSTIFICATION FOR THE RESEARCH

Preamble

The thesis forms part of an Innovation Partnership research project entitled “*Low Noise Solutions for Night Deliveries*” which was initiated by the Department of Transport Engineering, DIT, in October 2005 and completed in October 2007. The author was the lead researcher and the project manager was Ms. Roisin Byrne assisted by Mr. John Grimes (DIT, 2007).

This Innovation Partnership set out to develop low noise products and solutions to enable Irish logistics service providers to carry out night deliveries to city centre shops in a more sustainable manner acceptable to residents. The research was also designed to underpin the noise policies being considered by Dublin City Council in accord with EC and national regulations whereby action plans incorporating noise limits for traffic are being formulated. The Innovation Partnership was funded to the value of €263,000 by a consortium of public and private bodies which comprised Dublin City Council, Enterprise Ireland and major city centre retailers, logistics service providers, the Dublin City Centre Business Association and Irish based equipment suppliers.

“*Low Noise Solutions for Night Deliveries*” was seen as a practical follow-up to a research project entitled “*Sustainable Freight Distribution in a Historic Urban Centre*”. This project was completed in November 2004 and was initiated and conducted by the author and by Ms. Clare Finnegan under the direction of Professor Margaret O’Mahony at the Centre for Transport Research at Trinity College Dublin. The project, which was funded by the Department of Transport and by the Higher Education Authority, proposed more night deliveries for shops in Dublin city centre in order to help ease peak congestion and to free up customer access to retail stores during the day (O’Mahony, Finlay and Finnegan, 2004).

The research at Trinity College gave new insights into the rhythms and patterns of urban deliveries, based on a street by street survey of 1,400 deliveries to 160 premises

in the city centre. This analysis was supported by an examination of the operations of selected major logistics service providers.

One of the key recommendations put forward for easing congestion at peak times and for improving logistical efficiencies was to encourage more night-time deliveries. It was recognised however that night delivery operations cause annoyance to residents and that the development and deployment of low noise equipment and changed behavioural patterns should therefore be encouraged to mitigate the nuisance caused.

The challenge to develop low noise solutions and products was therefore the objective of the follow-on Innovation Partnership programme. Participation in the programme consortium was seen by the retailers as a way of maintaining the goodwill of their local customers, by Enterprise Ireland and by Irish suppliers as affording a commercial opportunity to bring new acoustic products to market and by Dublin City Council as a way of enhancing the attractiveness of urban living, of promoting a more sustainable transport solution for city freight deliveries and of underpinning the requirement to develop noise action plans in accord with the European Directive on Noise (EC, 2002).

A review of developments both internationally and nationally indicated that while there are powerful factors driving the trend to urban night deliveries, there is a requirement to conduct these operations in a sustainable way that will not unduly harm the quality of life or health of residents.

1.0. Introduction

1.1. Factors driving change to quieter night deliveries

The “drivers” accelerating the trend to night deliveries and the consequent need to mitigate the nuisance caused were found to be: (1) the growing public awareness of the health effects of noise, (2) the changing logistics patterns consequent on 24/7 urban living, (3) the requirements of the European Noise Directive and national guidelines, (4) Dublin City Council’s Heavy Goods Vehicles (HGVs, see *Glossary of*

Terms) strategy following the opening of the port access tunnel in February '07 and (5) the commercial benefits accruing to distributors by being able to avoid day time congestion.

The factors or “drivers” which have influenced the noise abatement policies and responses to mitigating traffic noise in Dublin are illustrated in Figure 1.1.

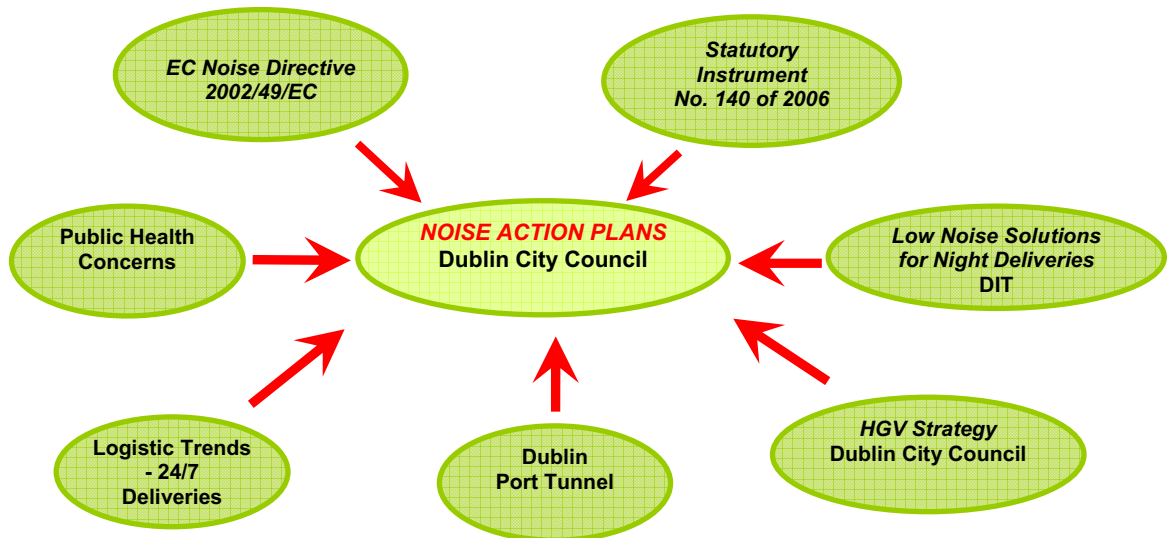


Figure1.1. Factors influencing noise abatement policies and the trend to night deliveries.

1.2. Health effects of traffic noise

The European Commission recognises environmental noise as a serious environmental problem (EC-CALM, 2004). According to the Commission, within the EU, 80 million people suffer from unacceptable levels of noise and a further 170 million live in ‘grey areas’ where they are exposed to serious annoyance. A body of research by Rust and Affenzeller (2004), sponsored by the EC under the *CALM* programme confirms the detrimental impact on health of sleep deprivation caused by traffic noise. Noise pollution is estimated to cost the EU countries from 0.2 % to 2.0 % of GDP. The lower estimate of 0.2 % would represent an annual financial loss of € 12 billion and the higher estimate would entail an annual loss of € 120 billion (EC-CALM, 2005).

In German cities more than one third of the population is seriously affected by road traffic noise. Night time noise levels have increased by 3 dB(A) in the past decade as growing traffic intensity has concentrated on the night according to the German 'Quiet Traffic' initiative (Leiser Verkehr, 2005). A-weighted decibels (dB(A)) are defined in chapter 2.

Other examples of national research programmes similar to the German 'Quiet Traffic' initiative mentioned above were the French 'Predict' programme (Predict, 2005) and the Dutch 'PEAK' programme (PEAK, Senter Novem, 2005). To these international programmes can now be added the DIT led Innovation Partnership which has been brought to the attention of the EC through presentations to sponsored workshops hosted by the BESTUFS, POLIS and SILENCE research networks (BESTUFS 2006; POLIS 2007; SILENCE 2006).

In 1997 the EC responded to the increasing severity of noise disturbance brought about by growing traffic volumes with a Green Paper on '*Future Noise Policy*' that recognises noise as one of the main environmental problems (EC, 1997). This in turn prompted the development of a coherent Directive on noise (EC, 2002). This Directive is currently supported by two EC research initiatives, the 'CALM' and "SILENCE" programmes (EC, 2006). The "CALM" programme supports the development of a common methodology for noise mapping across the EU whilst "SILENCE" promotes best practice for noise abatement and the commercialisation of low noise products and solutions.

The stated aim of the EC Green Paper (1997) is that 'no person should be exposed to noise levels which endanger health and the quality of life'. Long term visionary noise reduction targets of 10 dB(A) from individual road traffic vehicles are foreseen as achievable by 2020 (EC, 1997). The EC therefore promotes the development of technologies that can meet this objective and related noise reduction targets. According to the EC Green Paper, traffic noise at levels above 30 dB(A) experienced by residents in an indoor environment can cause sleep disturbance and recommends that noise levels in the home should not generally exceed 40 to 45 dB(A). Indoor noise levels of 40 dB(A) are regarded by the EC as the critical load beyond which nocturnal indoor noise begins to become intolerable, while the World Health Organisation

regards less than 30dB(A) as a reasonable ‘noise level during the night for a sleep of good quality’ (WHO, 2008).

The EC Noise Directive aims to define a common approach for combating the harmful effects of exposure to urban noise, to establish common monitoring indicators, to prepare strategic noise maps and to develop action plans for noise abatement (EC, 2002).

In compliance with the EC directive, Dublin City Council is required to submit action plans to the Commission during 2008 and to suggest acoustic limits for night deliveries in order to minimise the risk to health of the affected vulnerable populations. An important objective of the DIT led Innovation Partnership project was to advise the city council on a possible range of acoustic limits that would be most likely to find wide acceptance by all the parties concerned and that would have regard to the trade-offs between the social benefits accruing to the residents and the likely additional costs to the retailers and distributors for adopting noise abatement measures.

In 2005, the British Building Research Establishment reported on a comprehensive survey of environmental noise and of the population attitudes to exposure in England and Wales (BRE, 2002). This ‘UK Noise Incidence Study’ involving 1,160 measurements, 24-hour noise measurements at a sample of dwellings and 5,500 interviews, indicated that the majority of the population now lived in homes exposed to noise levels above those recommended by the World Health Organisation (WHO Guidelines, 1999). Recent years have seen an increase in UK noise levels at night, resulting in a shorter noise free night and a reduction in the noise level differences between day and night. The proportion of respondents in England and Wales currently affected by road traffic noise now stands at 54 %.

Of relevance to night time traffic disturbances is a study reported by the European Heart Journal with contributions from Lars Jarup based at Imperial College London, which confirms that night time aircraft noise causes significant damage to health even while people are sleeping (European Heart Journal, Haralabidis et al. 2008, pp.658-64). The researchers found that 140 sleeping volunteers in their homes near Heathrow

airport suffered noticeable increases in blood pressure after they experienced a “noise event”, i.e. a noise louder than 35 dB (linear weighted rather than A-weighted) such as an aircraft passing overhead, traffic passing outside or a partner snoring. The effect could be seen even when the volunteer was not consciously disturbed. The increases in blood pressure were related to the loudness of the noise – for every 5 dB increase in aircraft or by-pass traffic noise at its loudest point, there was 0.66 mmHg increase in systolic blood pressure. Aircraft and road traffic noise events caused instant increases in systolic blood pressures of 6.2 mmHg and average increases in diastolic pressure of 7.4 mmHg. It was concluded that an increase in night-time aeroplane noise of 10 dB increases the risk of high blood pressure and hypertension in both men and women by 14 %.

In an earlier study relating to traffic noise reported by the European Heart Journal (Willich et al. 2005, pp.276-82) it was concluded that:

Chronic noise burden is associated with the risk of myocardial infarction. The risk increase appears more closely associated with sound levels than with subjective annoyance.

Due to the concerns that night deliveries can cause noise disturbances which may compromise the quality of life for urban residents, many European cities are facing up to the challenges of managing deliveries in a more sustainable manner by seeking to impose noise restrictions in designated noise sensitive zones and are sharing their experiences through participation in the “CALM” (2005) and “SILENCE” (2005) research networks mentioned earlier. Dublin City Council and DIT have contributed to these developments and interactions through membership of these European networks (Finlay and McManus, 2006).

1.3. Response by Dublin City Council to the EC directive

As stated in section 1.1, Dublin City Council responded to increasing complaints and litigation by residents and to the requirements of the EC Noise Directive and related national guidelines such as Statutory Instrument 140, by completing noise maps to

identify the most vulnerable populations, by considering appropriate action plans and by supporting the DIT led Innovation Partnership, all with a view to abating noise nuisance (EC 2002; Irish SI 140 2006).

In April 1999 the city council began to prepare a strategic noise map of the inner city between the north and south circular roads. This exercise was designed to feed into the EC “CALM” thematic network that monitors and harmonises the progress of noise mapping in European cities which have populations of 200,000 or more. A proprietary noise model and software called ‘Predict’ was used to develop innovative maps linking noise level bands and contours to land use patterns, to the populations affected and to traffic data (EC, 2004). A noise map of the city centre area bounded by the canal cordon is illustrated in Figure 1.2.

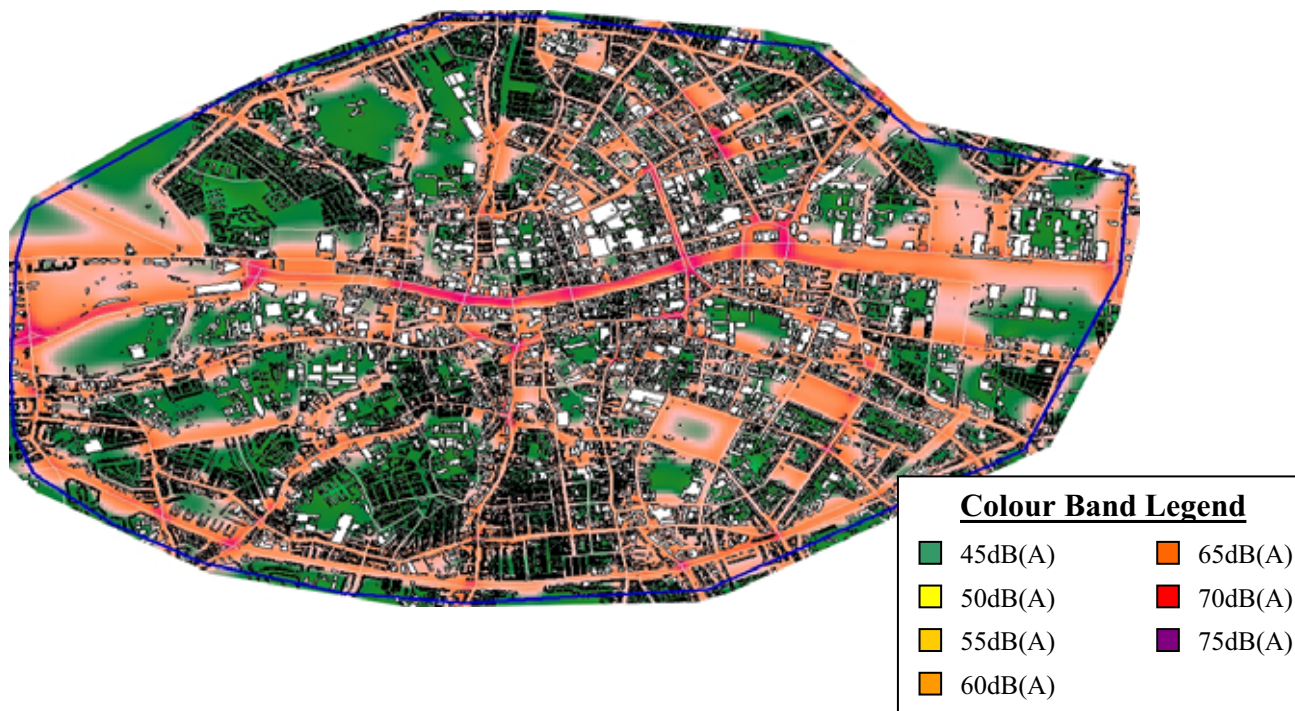


Figure 1.2. Noise map of Dublin city centre – courtesy of Dublin City Council

Noise maps for the city centre and adjacent areas coupled with data on traffic flows and patterns forms the basis for action plans to be submitted to Brussels by the City Council by the end of 2008 in accord with the requirements of the EC Directive.

1.4. Heavy goods vehicle strategy for Dublin

The Heavy Goods Vehicle (HGV) strategy introduced by the city council in February 2008 following the opening of the Dublin port access tunnel has encouraged the movement of deliveries by 5 axle trucks to the night and the noise mapping exercise described earlier can provide a benchmark for monitoring the increase in noise disturbance that is likely to arise as a result.

The location of the port tunnel is illustrated in Figures 1.3 and 1.4 and the city centre area affected by the HGV strategy and day-time curfew on large HGVs is shown in Figure 1.5.



Figure 1.3. Map showing the route of the Dublin port tunnel and M50 ring road



Figure 1.4. Photograph showing the Dublin port access tunnel



Figure 1.5. Map showing city centre cordon boundary for HGV day-time curfew (Dublin City Council, 2008)

A recent survey by Dublin City Council found that the HGV strategy has successfully met its objective of removing between 70-90 % of five axle HGVs from transiting the main routes through the historic city centre between the curfew hours of 7.00 am to 7.00 pm. This is a substantial reduction in heavy goods traffic considering that 65 % of HGVs accessing the port are 5 axle trucks or more (Finnegan and O’Brien, 2007). The extent to which deliveries by five axle HGVs has been moved to the night as a result of the curfew has yet to be quantified but it is thought by the logistics service providers to be significant.

1.5. International overview

A review of how other European countries and cities have responded to the need to abate urban traffic noise was carried out through access to the EC thematic networks mentioned earlier, namely SILENCE, CALM and BESTUFS (EC, 2002-2007). It was discovered that the Netherlands has developed very relevant experience through the government sponsored “PEAK” programme. Other instructive examples were those reported from France, Spain and from British cities under the auspices of the Noise Abatement Society (Noise Abatement Society, 2005-2007). It was realised on completion of the review, that there is “no one size fits all” model and that while new

acoustic solutions have been successfully brought to the Dutch market, there is still scope for product innovation and adaptation to suit Irish needs and to reduce the additional costs of “going quiet”. The conditions and topography in Irish cities are unique and different to those to be found on the European continent in terms of a relatively cold climate, low population densities and urban foot-prints, low rise buildings and the types of construction materials used on pavements and facades.

1.5.1. The Netherlands and “PEAK”

The sustainable physical distribution of goods and services in urban areas in the Netherlands where 89 % of the inhabitants live, features high on the Dutch political and economic agenda. In urban areas, it is estimated that commercial distribution accounts for 6 % to 10 % of all traffic movements.

In order to promote a public private partnership in sustainable logistics, the Dutch Forum for Physical Distribution in Urban Areas (PSD) was established in 1995. The forum has evaluated the possible access regulations and permitting measures which help to promote sustainable solutions. The PSD serves as a networking organisation for all the parties involved in the supply chain and it has helped to place city freight distribution high on the public policy agenda. The forum facilitates the exchange of information on developments in 290 different municipalities. The forum encourages a uniform approach for establishing a vehicle entry regime in the Dutch municipalities for vans and trucks of 3.5 tonnes and upwards. The regulatory regimes are of sufficient duration (5 to 7 years) to encourage the development and implementation of innovative solutions.

The Environmental Retail Trade & Traditional Crafts Decree, promulgated in 1998, brought the question of alleviating peak noise during loading and unloading into the spotlight. This order currently affects 65,000 Dutch companies and covers distribution activities in all the urban residential areas. To overcome the difficulty of complying with the stringent noise level standards proposed for governing loading and unloading, the authorities responded by setting up the PEAK programme; ‘Places, People & Products - Solutions for night distribution’. The programme has encouraged the market to adjust to the noise decree and to examine the quality of life and the

economic and technical feasibility issues involved. A range of technical modifications and new products that are necessary for delivery vehicles and related ancillary equipment to achieve an acceptable level of acoustic nuisance was developed. “PEAK” is led by the Dutch Ministry of Housing, Spatial Planning & Environment and is implemented by the technical development agency, Senter Novem.

The targeted noise levels with respect to the retail trade was set at 65 dB(A) for the evening and at 60 dB(A) for the night and the early morning hours as can be seen in Table 1.1.

Table 1.1. ¹Dutch legislation for urban noise levels for the evening and night

Period	Peak noise level
07.00 – 19.00 hrs	No level applies
19.00 – 23.00 hrs	Peak level of 65 dB(A)
23.00 – 07.00 hrs	Peak level of 60 dB(A)

The “PEAK” programme comprised ten projects which focused on (1) the transfer of knowledge (2) promoting quiet behaviour (3) modifications to loading and unloading locations and architectural design (4) developing low noise delivery trucks (5) quiet ancillaries including roll-cages, trolleys and fork-lifts (6) electric accessories such as reversing beep and torque limiters. The solutions and products demonstrated by the PEAK programme were evaluated in terms of their technical and economic feasibility. Methods for measuring peak noise during loading and unloading were designed by the Dutch technical consultancy company, TNO. The effectiveness of various noise reduction measures was quantified and comparisons made between different products.

The low noise ancillaries and systems under development in the Netherlands were deemed to be suitable for further adaptation for the Irish market by home based suppliers. Because of their valuable experience in managing “PEAK”, Senter Novem were invited to participate in the Innovation Partnership consortium. The aim of the Innovation Partnership was not only to promote best practice for night deliveries but also to add novelty to the work already accomplished by “PEAK” and by other potential overseas suppliers.

¹ The Dutch Authorities set the limits in terms of true peaks or waveform peaks which are defined as the maximum positive dynamic excursion from a zero level of any waveform (BKSV, 2008)

1.5.2. France

GART is a consortium of French municipal authorities concerned with promoting sustainable traffic management solutions and has reported on the situation regarding out of hours deliveries. GART felt that there was scope in many French cities for greater peak separation between the patterns for people movement and for goods movement. Surveys conducted by GART found that delivery and pick up rhythms varied according to the field of activity and to the types of businesses being served. Although the frequency of deliveries was increasing in French cities, this trend was constrained by the traditional late opening of stores, many of which do not open until after 10.00 am and by dwell time delivery restrictions on the streets

Despite these constraints, many French municipalities see night time deliveries as a worthwhile and viable solution for easing congestion and this practice is strongly encouraged by the authorities in Dijon, Orleans, Marseilles and Paris. On the other hand, cities like Lille and Rennes reject night deliveries because of the noise nuisance and the anticipated complaints by residents. The GART view tends to favour the establishment of city centre “relay centres” or shared drop-points that can be quickly replenished at night and having local distribution organised during the day. The extension of the time limits for morning deliveries and the incremental development of low noise technologies and systems is seen by GART as offering realistic near term solutions.

1.5.3. Spain (Barcelona)

Barcelona has considerable experience of managing city freight in a sustainable manner. Zone access restrictions have been implemented in the city centre to give privileged access to low emission and to low noise vehicles. Restrictive measures were first implemented 20 years ago in order to ease the traffic congestion in the historical centre and these have been successful.

Rising bollards and gates protect three restricted zones. Entry to the zones is possible at certain times only – vehicles may not access the zones between 11am and 3pm or between 5pm and 8pm. and deliveries and other commercial visits must be made

outside of these hours. Entry to the zone is controlled by the use of swipe cards or by telephoning a control centre. The authorities have sought to encourage the use of low noise equipment and of eco-friendly vehicles.

1.5.4. England and Wales

In response to the EC Noise Directive, noise maps and action plans are being developed for the City of London and for other large cities. Noise abatement initiatives have been taken as a part of a wider policy to promote sustainable transport by the authorities in a number of cities and some such as Doncaster and Wandsworth, have been promoted by the Noise Abatement Society (NAS) with which DIT has collaborated. According to research results reported by the NAS in their newsletters, noise complaints by residents have increased five-fold in the last five years and an increasingly noisy environment has affected productivity in the work place and has contributed to ill health (NAS, 2008).

In England and Wales, traffic related issues of topical concern, including noise nuisance, are often dealt with by Freight Quality Partnerships or FQPs which serve as an effective consultative forum for all the parties concerned. 'FQPs' were first established in the mid 1990's and by 2003, thirty partnerships were in place. FQPs have helped to achieve agreements on routing, load sharing, town centre access and permitting controls. Agreed procedures to enhance sustainability have been put in place by councils in Hampshire, Southampton, Ripon, Northampton, Leicester and Nottingham.

1.6. Delivery patterns and rhythms in Dublin city centre

Research completed by the author at Trinity College Dublin (TCD), as referred to in 1.1, gave new insights into freight movements in the city centre; this showed that the city now needs to cope with new rhythms and patterns affecting deliveries. These patterns were found to be driven by the "24/7" city living, the demand for just-in-time deliveries, the unwillingness of retailers to hold stock, by the e-society and internet shopping.

The logistics data was based on a sample size of 1,400 deliveries to 160 stores and the data was evaluated under a number of headings including (a) the categories of goods delivered to the stores as shown in Figure 1.6 and (b) the dwell times at the different premises as shown in Figure 1.7.

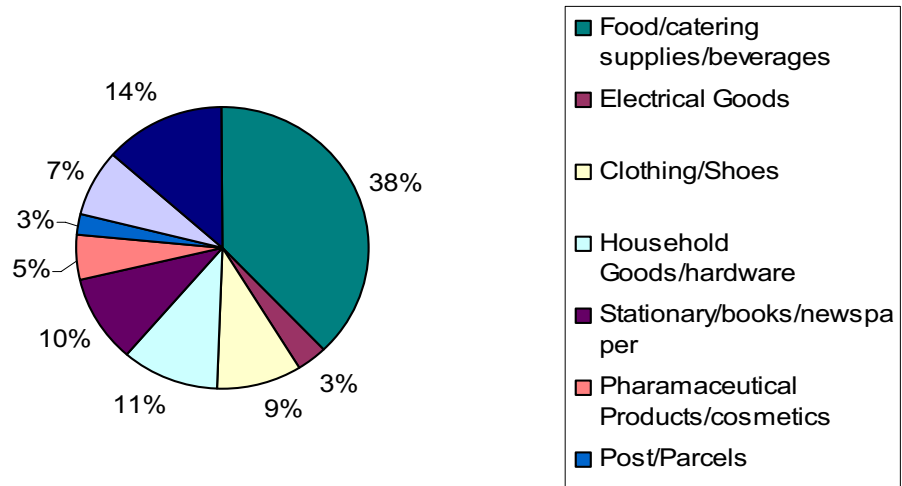


Figure 1.6. Types of goods delivered to 160 city centre stores (O'Mahony, Finlay and Finnegan, 2004)

It can be seen from Figure 1.6 that deliveries of foodstuffs accounted for the highest proportion of city centre deliveries at 38 %.

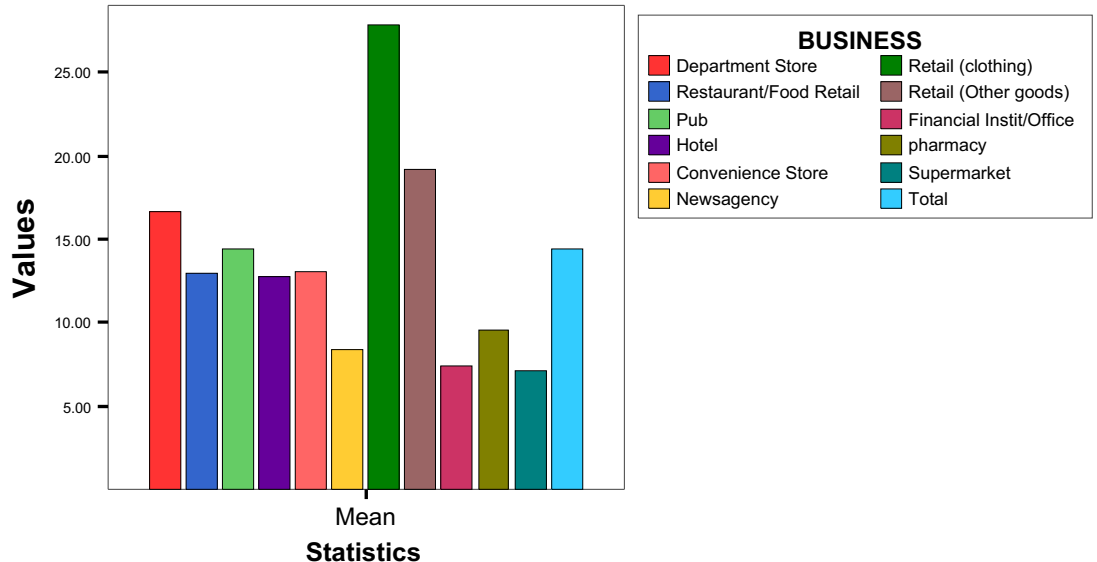


Figure 1.7. Dwell times in minutes for night time deliveries by type of premises (O'Mahony, Finlay and Finnegan, 2004)

The TCD data indicated that the mean dwell time for delivery trucks was 14 minutes as can be seen from Figure 1.7 and that 39 % of deliveries made by HGVs to the city centre were at the kerb-side. The dwell times varied across different business types; for example deliveries to drapery shops had an average dwell time of 26 minutes

while deliveries to offices and finance houses had a dwell time of only 7 minutes. These findings were seen to have implications for city centre accessibility both for pedestrians and for overall traffic during the day, and for causing noise disturbance during the night and early morning.

As a part of the Innovation Partnership, the National Institute for Transport Logistics (NITL / DIT, 2006) which is a part of DIT, was asked by the author to manipulate their data basis to ascertain the delivery times for consignments from six major out of town distribution depots to premises within the M50 ring and within the canal cordon/central business district. Logistics data from ten different food companies totalling 2,509 actual deliveries was examined to determine the spread of delivery times during a one week period.

Figure 1.8 shows the spread of delivery times across the 24 hour day for 2,509 drops within the M50 motorway ring and within the central business district (CBD). Of the total of 2,509 deliveries tracked within the M50 ring, 828 took place within the canals. Within the M50 ring 15 % deliveries take place before 7am congestion peak and the busiest period was between 8am and 9am when 15 % of deliveries occurred. In contrast, within the canal cordon a higher proportion or 24 % of deliveries took place before the 7am peak. It was found however that some 16 % of food deliveries still occurred within the canals between 8am and 9am which coincides with the morning congestion peak.

The pattern of deliveries is likely to have moved significantly to the early morning since the data was collated in 2004 and following the implementation of the HGV strategy in February 2007 restricting access to the city centre by large HGVs during the day between 7.00am and 7.00pm.

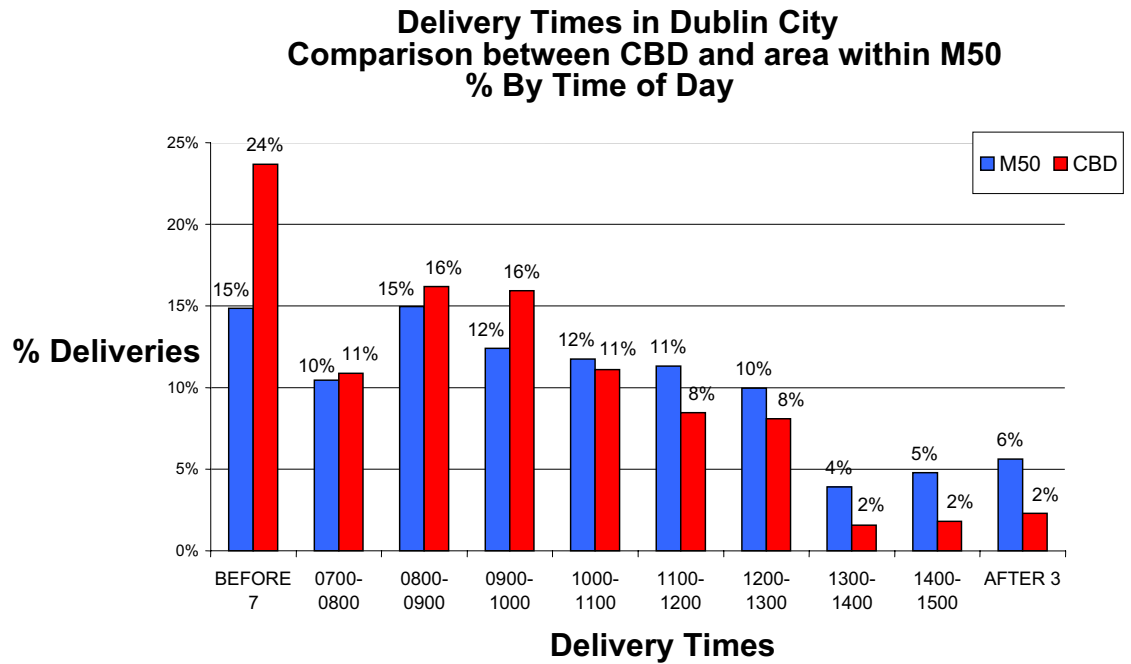


Figure 1.8. Comparison of delivery times between central business district and the area bounded by the M50 ring road (NITL / DIT, 2006)

The location of the drop points within the canal cordon is shown in Figure 1.9 and all of these deliveries originated from six depots as shown also in Figure 1.9.

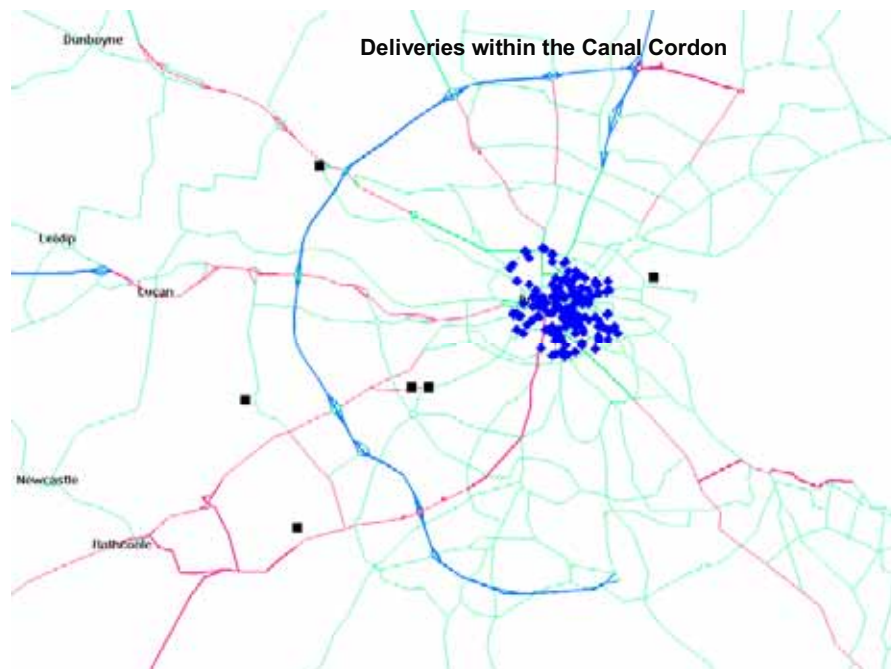


Figure 1.9. Drop from 6 depots to points within the canal cordon (NITL / DIT, 2006)

An example of a typical kerb-side delivery to an inner city convenience store by a five axle HGV is shown in Figure 1.9.



Figure 1.10. Photograph showing a typical kerb-side delivery to a city centre store

1.7. Case study demonstrating savings from moving to the night

At the request of the author, a hypothetical case study was formulated by NITL in order to estimate the likely savings to a logistics service provider by changing from day time to night deliveries (NITL / DIT, 2006). The case study was based on the operations of a distributor of temperature controlled foods who uses five 17 tonne rigid trucks to service the area within the M50 ring. NITL analysed a week's activity and modelled it using the proprietary distribution planning software. The sample size comprised 636 deliveries involving an average of 21.2 drops per day for five trucks for six days during one week.

The NITL model indicated that four drivers on night duties could do the work currently done by five. Significant cost savings would accrue due to a significant decrease in the time taken to get to and from the outlying depot to the city centre. The time otherwise spent stuck in traffic and trying to find parking would be devoted instead to 'productive' work. It was estimated that the distributor would save € 80,000

per annum by moving to the night and by being in a position to take one truck and a driver off the road and by saving on fuel costs.

1.8. The Innovation Partnership - “Low Noise Solutions for Night Deliveries”

As mentioned earlier this thesis forms a part of the research that was conducted under the Innovation Partnership. A consortium of commercial partners and the municipal authority worked closely with DIT to develop low noise, low cost products and materials which could be sourced locally and be easily adapted for the Irish market. Products selected for development included; floor and side-wall linings and coatings for the HGV trailer units; tail lift coatings; silent refrigeration systems, quiet roll-cages, portable kerb-side ramps and mats, forklift truck exhausts and delivery site acoustic docking bays. The author participated in all aspects of the Innovation Partnership but focused especially on the initial field trials which identified the events which caused the peak sounds and annoying frequencies and on developing acoustic damping solutions for the vibrating floors and panels of the HGV trailer and tail-lift platform and on attenuating the high frequency sounds caused by the manipulation of the steel roll-cages. The conduct of this research is described in the later chapters.

On completion of the Innovation Partnership a number of new products had been successfully demonstrated and tested (1) a new water based acoustic coating (2) a “hush-kit” for retro-fitting to the steel roll-cages (3) a portable ramp for kerb-side deliveries (4) an acoustic docking bay for logistics sites (5) a “quiet” exhaust system for fork-lift trucks (6) remotely controlled “silent” refrigeration.

The Innovation Partnership was seen by Dublin City Council as providing a useful basis for formulating action plans for traffic and for setting realistic and broadly acceptable acoustic limits for night deliveries in accord with the EC Noise Directive (EC, 2202).

1.9. The commercial case for developing HGV related acoustic products

It was assumed that the demand for acoustic products and modified HGV ancillaries is driven by the sales of trucks which conform to the pending EC related urban noise regulations. The trends in HGV sales were therefore evaluated and a close examination was made of the significant market for low noise products in the Netherlands, a new market which is expected to emerge in Ireland following the formulation of the EC related noise action plans by the four municipal authorities in the greater Dublin area in late 2008.

As a part of the Innovation Partnership, an assessment was made of the likely markets for low noise HGVs and related ancillaries in Europe and in Ireland. This exercise involved a review of the trends in the HGV markets in western Europe and in Ireland. Assistance was sought from a Scottish based marketing intelligence consultant, *Schmidt's Truck Aid Ltd.* (Schmidts Truck Aid, 2005).

The market intelligence indicated that seven in ten of the heavy vehicles (greater than 16 tonne gross vehicle weight) sold in Western Europe fall into the expanding category of articulated trucks which are increasingly used for 'round the clock' deliveries and for country and continental-wide trips. The demand for low noise heavy goods vehicles (HGVs) which have the flexibility to access urban areas at night and to transit low noise emission zones was found to be on the increase. This trend is expected to accelerate when cities bring into force action plans in accord with the EC Noise Directive.

According to the Schmidt's review of European markets, sales of trucks of 3.5 tonne gross vehicle weight (GVW) and over, in 2004 were 335,981 of which the heavier trucks of more than 16 tonne GVW accounted for 230,700 or 69 % of total sales, reflecting a significant trend towards the bigger vehicles. Between 2003 and 2004 sales of trucks of 16 tonne GVW increased by 8 % while sales of smaller 6 tonne trucks declined by 3 %. The forecast for 2011 was for an increase of total sales to 370,400 trucks of which 257,100 will be over 16 tonne GVW.

A trend towards the use of bigger HGVs for ‘round the clock’ deliveries coupled with the requirement to access urban areas and to respect noise restrictions is expected to accelerate the demand for the heavier low noise modified HGVs and ancillaries. These trends in the market will create new business opportunities for the suppliers.

1.9.1. HGV sales in Ireland

The market intelligence provided by Schmidts Truck Aid suggested that Irish sales of new HGVs of 16 tonne GVW and over, will range from 2,400 units to 3,200 units per year during the five years from 2004 to 2010 and that most of these vehicles will need to respect low noise restrictions if they are to have ready access to noise sensitive residential areas during the night (Schmidts Truck Aid, 2005). The value of these HGV sales was estimated to amount to € 300 million per annum and this volume of activity can be expected to benefit locally based HGV trailer body builders and the suppliers of ancillaries and acoustic materials.

It was assumed that the floors and side-walls of new HGV trailer units (3,000 per year) would need to be fitted with acoustic materials to meet the EC requirements and that these could be applied locally. It was also assumed that low noise roll-cages could also be sourced or retro-fitted in Ireland and on the basis that each large HGV contains up to 48 cages and that the population of roll-cages in the country amounts to 200,000. This activity could also create significant commercial opportunities for local suppliers.

1.9.2. Sales of “Quiet Products” in the Netherlands

As mentioned earlier the Dutch “PEAK” programme has stimulated the development and sales of “quiet products” by a combination of noise limit regulations for night deliveries and the provision of government subsidies.

According to Senter Novem, sales of quiet products in the period 2004-2008 were valued at € 60 million and 17,000 units were sold. The sales were supported by a government subvention of € 6 million which has now ceased because the technology is deemed to be approaching maturity (BESTUFS, 2007).

The prices for low noise products in the Netherlands were found to be from 10 % to 15 % higher than for standard products and these have merited “type” approval under the PEAK programme. The Dutch suppliers see low noise products as a promising growth area and realise that many of the bigger logistics providers are willing to pay a premium for low noise products if this permits them to access noise sensitive areas and to comply with international and national standards. Similar opportunities present themselves to Irish suppliers.

1.10. International research on traffic noise abatement

The EC has supported significant research into the wider area of traffic noise and night deliveries can be considered in this context. The EC SILENCE programme supports the development of technologies which can attenuate traffic noise (SILENCE, 2005). The SILENCE initiative brings together more than 40 partners comprising vehicle manufacturers, equipment suppliers, municipal authorities and research institutes which include DIT. Irish participation ensures an awareness of best practice and access to ongoing R&D results throughout the EU.

The SILENCE programme addresses how the different identifiable sources of traffic noise such as tyres, engines, transmission and exhausts might best be attenuated. Whilst the EC programme has focused on by-pass traffic noise rather than on night deliveries, the development of quieter diesel engines and exhaust systems for HGVs by the automotive industry would be beneficial.

As a part of the EC “CALM” programme, the potential levels of noise reductions in dB(A) expected from the exploitation of the different identifiable sources have been assessed and targets have been set. A ‘road map’ for research into noise attenuation possibilities has been agreed and the potential noise reduction targets and research requirements for road traffic are listed in Figure 1.11 (CALM, 2005-2008).

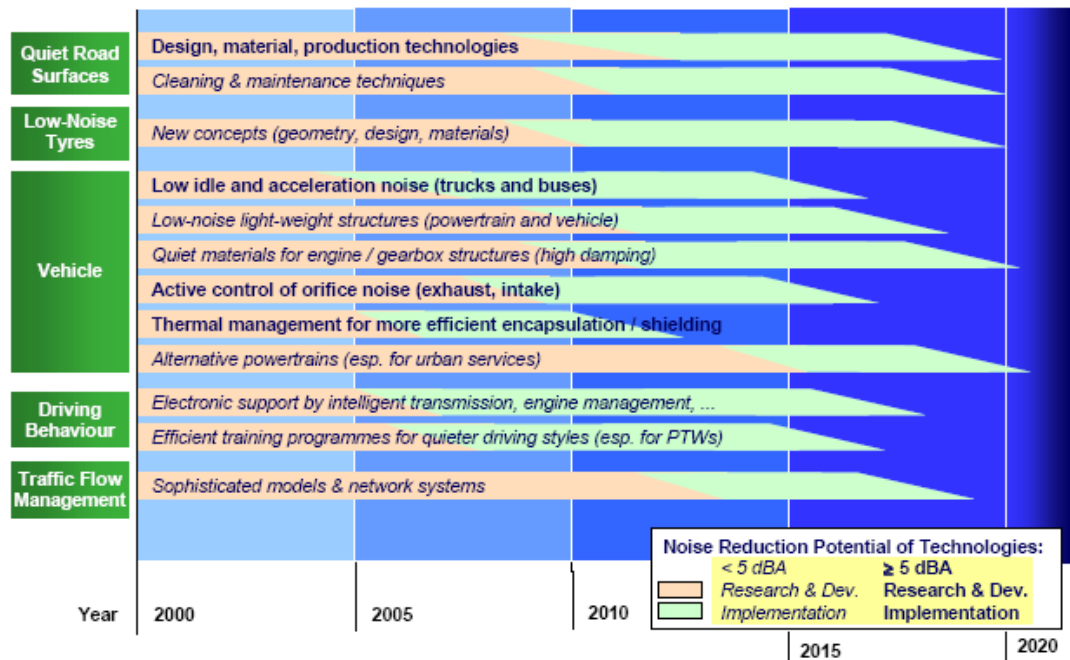


Figure 1.11. Noise reduction potential from different R&D activities as foreseen by the EC-CALM programme (Rust and Affenzeller, 2005)

The European Commission has taken a ‘systems approach’ to developing its R&D programmes for the attenuation of traffic noise and proposes a cost benefit approach to future investment. The EC attaches great importance to the interaction between research and the formulation of realistic national policies and regulations. The development of quieter night delivery operations has a contribution to make to this agenda.

1.11. Discussion

A number of powerful factors were found to drive the trend to night deliveries; 24/7 shopping, the desire by distributors to avoid congestion peaks, just in time deliveries and e-logistics, the desire by retailers to free up customer access to their premises. Earlier research conducted by the author at Trinity College Dublin gave new insights into the patterns and rhythms of deliveries to shops in the city centre, particularly with regard to the parameters which have relevance for noise disturbance such as deliveries by time of day, the dwell times at the kerb-sides and the types of goods delivered. It was also found that unlike many other European cities, a large proportion of deliveries

to Dublin stores are made at the kerb-side rather than to dedicated or underground logistics sites (O'Mahony, Finlay and Finnegan, 2004).

The trend to night deliveries in Dublin was also evident from a NITL / DIT survey which showed that in 2005 within the canal cordon, 24 % of all deliveries of temperature controlled foods were made to shops before the 7am congestion peak. This trend is likely to have accelerated following the introduction in February 2007 of the HGV strategy and restrictions on five axle trucks by Dublin City Council and this will strengthen the case for a more sustainable approach to night deliveries.

A compelling social and “public good” justification can be made for supporting research into mitigating the potential damage to health caused by night-time disturbances. As mentioned in section 1.2, estimates by the EC of the social and economic costs of traffic noise were found to be very substantial. The damaging effect of sleep deprivation was found to be supported by a significant body of medical research into the health implications of traffic and aircraft noise by bodies such as the World Health Organisation.

Public concern with noise pollution has moved up the European political agenda. In the interests of ensuring a satisfactory quality of life for residents many municipal authorities supported by EC through its noise directive, were found to have taken steps to mitigate the nuisance caused. DIT through the collaborative Innovation Partnership, “Low Noise Solutions for Night Deliveries”, has helped to place Dublin as a significant player in this debate. This research forms part of the Innovation Partnership and, as will be seen in later chapters, has focused on developing solutions for attenuating peak noises caused by the manipulation of steel roll-cages inside the HGV trailer units and along the pavements during night delivery operations.

It was discovered that the future demand for low noise products in Ireland will be driven by (1) the growing trend to night deliveries in Dublin city centre (2) the implementation of action plans by Dublin City Council in accord with the EC Noise Directive and Statutory Instrument 140 (3) the numbers and sales of the larger HGVs that will require night time access to residential areas (4) increasing complaints to Dublin City Council and litigation by residents and (5) the acceptability to the

distributors and retailers of bearing the additional costs of acquiring and of retrofitting “quiet” products and acoustic materials.

Following an overview of international research on traffic noise, the Dutch “PEAK” programme was identified as having created a very relevant body of experience on which to build the DIT led Innovation Partnership. The Dutch government have, since 1998, set stringent noise limits for night operations in their major towns and have successfully encouraged the development and commercialisation of a new range of low noise products. A combination of regulations for night deliveries together with government subsidies has stimulated sales of “quiet” products to the value of € 60 million in Holland in the period 2004-2008.

Collaboration was arranged with Senter Novem in order to avail of and to build on their experience in managing the “PEAK” programme. Participation in other relevant EC acoustic research networks, namely “BESTUFS”, “SILENCE” and “CALM”, was also actively promoted. Having reviewed these international developments, it became evident that “no one size fits all” solution could be found to meet the needs of all cities and that there was scope to develop new products and solutions for selected niche applications in Ireland.

On the basis of market research it was predicted that demand for low noise products in Ireland will become significant if this demand is related to the sales of the heavier HGVs which are expected to grow to 3,200 per annum. A proportion of the existing HGV fleet may also require modification to carry low noise trailers, “quiet” roll-cages and other ancillaries if they are to enjoy access to “noise sensitive urban areas” when the noise action plans come into force in late 2008 in accord with the EC noise directive.

At the state of development in the Netherlands in 2007 there was found to be a cost penalty of from 10 % to 15 % for acquiring low noise products and to modify an HGV tractor and trailer. The challenge for Irish suppliers is to reduce the additional cost penalty for the particular products and acoustic materials which are within their capability to develop here. Because it can be shown that a convincing business case can be made for “moving to the night” in terms of the significantly better logistics

efficiencies accruing, these savings should be seen by the distributors and retailers as offsetting the additional costs of reducing the disturbances caused to residents.

The objectives of this research were to (a) identify the peak sounds, frequencies and the related events that occur during night delivery operations at the kerb-side (b) focus on the components of the HGV trailer unit and ancillaries that could be economically retro-fitted with acoustic materials and (c) attenuate the noise and signature frequencies associated with these particular events and components by the application of suitably selected materials.

To conclude, a clear justification can be made for undertaking the applied research described in the following chapters on both social and economic grounds. A review of developments internationally has indicated room for further innovation and adaptation to suit the conditions in Dublin city centre.

CHAPTER 2. RESEARCH METHODOLOGY AND LITERATURE REVIEW

2.0. Introduction

The aim of this chapter is to describe the approach and methodologies used for this research. A project plan and sequence of tasks was proposed and the appropriate standards and test procedures were selected and developed.

As mentioned in Chapter 1, a review of the literature and interactions with the local authorities indicated a growing public awareness of noise control issues. According to Bruel and Kjaer sound quality has emerged as an increasingly important aspect of product design and of industrial processes and has made acoustic material selection increasingly important for designers (Bruel and Kjaer, 2006).

Rather than considering a fundamental re-design of the equipment used in night delivery operations, the focus was on selecting suitable acoustic materials that could be easily retro-fitted. Consideration was therefore given to acoustic material testing which is the process by which the acoustic characteristics of samples are determined in terms of their absorption, reflection, damping and transmission loss (Bell and Bell, 1994, Chapter 6). The methods that are used to determine the acoustic properties of materials were examined and were found to involve exposing samples to known sound fields and measuring the effect of their presence on the sound fields.

The research methodology was devised to address the hypothesis that –

Acoustic materials are available or can be developed and applied to Heavy Goods Vehicles and ancillaries, which effectively and economically abate the noise caused by night deliveries

2.1. Outlining the tasks involved

A series of tasks were devised to identify the peak noise disturbances and frequencies caused by night deliveries and how these might be attenuated by the application of suitable acoustic materials.

Field trials to selected shops located in different urban streetscapes were first of all organised to identify the peak noises. A choice was made as to what standards might best be applied for this particular task having regard to national and international practices.

Sound analysers and suitable software were procured, courtesy of Dublin City Council, to help record the acoustic and graphic data collated from the night-time deliveries. This made it possible to record both the sound pressure level peaks and the signature frequencies associated with the different events.

The standards and protocols used by the Irish local authorities and the courts for dealing with noise complaints were considered and adapted as appropriate. It was found however that the UK standard, BS 4142 is the standard commonly used in Ireland by the Environmental Protection Agency and the local authorities (EPA, 2003). While this is the standard developed for measuring industrial noise, it has been adapted by the municipal authorities in Dublin to assess the impact on residents of disturbances on the streets including traffic related events. The parameters and theory underpinning BS 4142 and ISO 1996 were examined and these are described later in the chapter (British Standards, 1997 and ISO, 1996). It was practical and feasible to conduct the experiments described later in this thesis according to these recognised procedures.

The question of which category of acoustic material to apply was considered. The categories were found to comprise (1) absorption (2) transmission loss and (3) damping materials (Bell and Bell, 1994). Because the peak sounds that arise during deliveries (the banging of doors; raising of tail lifts; transiting of roll-cages; collisions with walls and floors) were found to be caused by impacts with resonating metal surfaces involving high frequency screeching noises, it was felt that the focus should

be on the application of damping materials. The reasons for selection and developing damping solutions are elaborated in more detail in chapter 4.

It was also appreciated that the criteria for selecting suitable acoustic materials should also involve an appraisal of their likely durability in fleet service and ease of application and thickness.

The acoustic pre-screening of acoustic materials in the laboratory was arranged before application in the field. A series of tests was designed to simulate the events that occur during delivery operations at the kerb side. Special test rigs comprising a falling weight and pendulum apparatus were fabricated.

The test rigs were used to evaluate the acoustic performance of an acoustic coating and the performance of this new material was compared in the laboratory with selected commercially available damping materials. The new coating was subsequently tested on board a “concept” HGV trailer unit located at a logistics depot.

A carousel test rig was also erected to evaluate the acoustic effectiveness of modifications to a standard mild steel roll cage involving the application of a “hush-kit”. The rotating carousel was designed to simulate the passage of a roll cage across the floor of an HGV trailer by rattling the roll-cage and recording the noise generated. The experiments were regarded as replicating under controlled conditions the events, peaks and associated frequency spectra occurring from the handling of rollcages during deliveries. In this way the effectiveness of the application of damping adhesive strips to different parts of the roll-cage (frames, castors, folding base etc.) could be assessed and a hush-kit package could be developed. The tests also involved colliding empty and partly loaded cages against a fixed obstacle and with other roll-cages and measuring the effectiveness of the hush-kit under these controlled conditions. These tests are described in Chapter 5.

A time and motion study was also carried out for the preparation and application of the hush-kit and this made it possible to assess the likely trade-offs between the acoustic effectiveness of the hush-kit and its costs and durability.

2.2. Focus on innovation

The challenge was to take this field of research forward in terms of additional innovation building on the reported results of the Dutch “PEAK” programme. While the “PEAK” programme identified the peak sounds that occur during deliveries, the associated signature frequencies were not examined with a view to matching these with the application of suitable acoustic attenuating materials. This aspect of the investigation was seen as bringing forward the research completed in the Netherlands and to have particular regard for the logistics patterns, urban topography and climatic conditions prevalent in Ireland. The particular methodology, experiments and test rigs used were also regarded as innovative.

2.3. The research strategy

A research strategy comprising eight different actions or tasks was proposed. A brief description and justification for these actions is given below.

Action 1: A review of national and international regulations and norms

European and Irish legislation was reviewed and the roles of the relevant agencies in Ireland such as the Environmental Protection Agency and the local authorities were also examined. The national and EC regulations which are an important driving force towards quieter traffic in cities are described in Chapter 1. The standard used by the Irish courts in response to complaints by the public and the rating methodology preferred by the Environmental Protection Agency under its “Guidance Note for Noise in Relation to Scheduled Activities” is British Standard 4142 (British Standards, 1997). According to this procedure a night time delivery may be assessed in relation to the ambient or background noise in the particular location (EPA, 2003).

Action 2: The social and commercial justification for this research.

It was desirable to justify this research in terms of the need to mitigate the social and health damage caused by sleep deprivation due to night time traffic disturbances. A

commercial justification should be made in light of the growing market potential for low noise products and materials in European cities that enforce low noise regulations. As reported in Chapter 1, similar public concerns and awareness was found to apply in Dublin.

Action 3: First set of field trials to assess the peak noise disturbances caused by kerb-side deliveries to shops.

Field trials were organised to identify the particular events that cause the peak sounds during kerb-side deliveries. A sample size of eight representative stores was selected where kerb-side deliveries occur in the early morning. The stores were located on both narrow and on wide streets which, because of their characteristic volumes of traffic, width and height of buildings, suffer different levels of by-pass traffic noise and reverberation.

The procedure involved measuring background noise for a period of about 5 minutes before a delivery occurred and then during the actual delivery operation which typically lasted for a dwell time of from 14 to 22 minutes. The peak noises were recorded in accordance with BS 4142 and could be attributed to the different events occurring during the delivery operation. This was done by matching the acoustic data with graphic data taken by a night vision camera which recorded the events taking place at the kerb-side. The weather conditions during each trial period were also noted.

B&K “Evaluator” software was used to analyse the field trials data and to develop the frequency spectra associated with the different peak events (Bruel and Kjaer, 2007).

Action 4: Materials selection & development

The objective of this task was to select suitable acoustic materials that might be applied to attenuate the peak sounds and signature frequencies identified in action 3. The different categories of commercially available acoustic materials were reviewed in order to select the most appropriate category. As described later in Chapter 4, it was

found that acoustic materials are classified under three headings (a) absorbing (b) barrier and (c) damping (Bell and Bell, 1994, pp.193-236). The application of damping materials promised to be the most effective way for attenuating the high frequency noises caused by the impacts and collisions of roll cages within the HGV trailer and onto the tail lift platform. As explained later in Chapter 4, the load carrying requirements and restricted dimensions of the HGV trailer unit could not accommodate the fitting of thick sound absorbing panels or of dense multi-layered barrier materials to the walls or floors of the trailer. The application of damping materials to the metal floors, tail gate platforms and kick-walls was seen as the most effective way of attenuating the high signature impact frequencies which were found to be generated by the handling of the roll-cages, as described in Chapter 3. On this basis it was decided to develop an acoustic coating which could be easily applied to the substrates used on the floors of the HGV trailers and tail lift platforms.

In the case of the steel roll-cages, the application of damping strips to the identifiable resonating parts offered a promising solution. The challenge as described in Chapter 5, was to develop a practical solution for attenuating the excessive noises created by the handling and stacking of the metal cages.

Action 5: Laboratory pre-screening of new acoustic coating

The objective of the laboratory trials was to evaluate the performance of a new water-based acoustic coating and to compare it with commercially available products. The experiments and methodology are described in detail in Chapter 4.

The standards used internationally for evaluating acoustic materials were reviewed and the application of special test procedures based on an adaptation of BS 4142 was considered to be appropriate (British Standards, 1997). In the absence of a vibrating bar or Oberst Bar apparatus which is commonly used for measuring damping characteristics, the damping coating was tested on a falling weight apparatus and on a pendulum test rig designed by the author and illustrated in Chapter 4.

The damping formulation was first of all coated onto small aluminium and mild steel panels and the sound generated by the repeated dropping of a machined weight was

measured using a procedure based on the ASTM standard for comparing the impact performance of different surface coatings (ASTM 2794, 1993). This test was repeated on larger 1 meter square coated panels, by impacting the panels with a suspended pendulum weight.

The new formulation was also compared with a selected proprietary coating and also with adhesive stripes of viscoelastic composites attached to the uncoated backs of the panels. The physical and wear and tear properties of the different coatings were also compared.

In order to investigate further the damping characteristics of the coating, its reverberation and decay characteristics were measured by attaching the pendulum apparatus to an oscilloscope, as described later in Chapter 4.

Action 6: Repeat of the laboratory tests on board the concept HGV

In order to predict how the acoustic coating might perform in the field, the laboratory tests were repeated on-board an HGV trailer unit located at a distribution depot. The tests involved transporting the portable pendulum and the falling weight devices to the distribution depot test site (as described in chapter 4), placing them on-board the HGV and measuring the sound emerging through the walls of the trailer when the coated 1 meter square aluminium panels were repeatedly impacted by the falling weight and by the pendulum. A falling weight test was also carried out on the mild steel substrate by placing a coated panel on the tail-lift platform and by recording the impact sounds. The noise attenuation results were compared with the earlier laboratory results obtained under the more controlled conditions indoors.

Action 7: Evaluation of modified rollcages

The field trials of deliveries to shops as described in Chapter 3 indicated that the manipulation of the roll-cages was a major source of peak noise. It was therefore decided to develop a “hush-kit” which could dampen the high frequency noises and which could be easily retro-fitted. The hush-kit comprised damping strips and rubber

stoppers which could be applied to the identifiable resonating parts of the steel roll-cages.

A special carousel test rig was constructed to evaluate the effectiveness of applying the components of the “hush-kit” to the different parts of a steel roll-cage. The rig was designed to simulate the transiting of roll-cages across uneven pavement surfaces. Tests also involved colliding empty and partly loaded cages against fixed barriers and with other cages and evaluating the acoustic effectiveness of the hush-kit under these conditions. The development and evaluation of the hush-kit is described in Chapter 5.

The durability of the acoustic formulation was assessed by transiting roll-cages repeatedly across a coated 1 meter square aluminium panel and measuring the resulting wear and abrasion.

Action 8: Overview of the research results and conclusions

Finally the research results were reviewed, conclusions drawn and recommendations made for continuing research including the possible investigation of certain unexplained phenomena.

2.4. Phasing and timing of the actions

At the inception of the project an outline project plan was proposed for the period October 2006 to January 2008. This outline timetable was generally adhered to and the phasing of the actions occurred as planned. The development of a sufficiently robust acoustic coating formulation by DIT-CREST for evaluation under controlled conditions was however more protracted than at first envisaged.

The tasks involving the literature searches, making a social and commercial justification for the project and the preliminary field trials of deliveries to shops, were all completed by June of 2007. The overall Innovation Partnership, of which this research is a part, was completed on time by October 2007.

2.5. Methodology used by the Irish authorities for measuring noise

It is not the intention to repeat in this dissertation the basic concepts of the study of vibration and noise as already described comprehensively in the literature and in the texts which were consulted during the course of this research. Basic theory was however studied initially in order to understand why particular procedures, standards and parameters are generally employed for assessing noise nuisance and in order to devise tests which could be applied to this particular project. The main texts, guidelines and regulations which were most frequently consulted are described in the bibliography. These included texts by Bell and Bell (Bell and Bell, 1994), by Smith and Peters (1996) and by Bies and Hansen (1988) and by Bruel and Kjaer (2006) as well as the relevant Irish environmental guidelines (Environmental Protection Agency, 2006) and the British and international standards on noise (British Standards 4142, 1997; ISO 1996, 1987).

It was noteworthy as mentioned earlier, that the preferred rating methodology recommended by the Environmental Protection Agency and by the municipal authorities is broadly in line with BS 4142 and the related ISO 1996 procedures and for this reason the parameters used in this protocol are explained below in the following section (EPA, 2003 and British Standards, 1997).

2.5.1. Parameters employed under British Standard 4142 and ISO 1996

British Standard 4142 (1997) prescribes a method for rating industrial noise affecting mixed and residential areas and may be used by the Irish authorities to assess disturbances caused by traffic related events such as deliveries to premises, rubbish collections and reversing trucks which ‘was revised in 1990 to align with ISO 1996 parts 1 to 3’ (BS, 1997, p.ii).

In accord with the BS 4142 standard, sound pressures are measured by a number of parameters such as LAF_{90} or LA_{eq} . For example LAF_{max} measures the maximum sound pressure level over short periods of time while LA_{eq} calculates the equivalent average of fluctuating sound pressures over a specified period of time. An accepted norm for measuring the disturbance caused by particular events is to compare the LA_{eq}

measured for the duration of the particular event with the LAF_{90} for the preceding background period. Peak sounds may be measured for a minimum period of 0.125 seconds.

The authorities generally perceive events which add 5 dB(A) or more to the background noise levels as causing serious annoyance to residents in the vicinity of the noise source. In other words, if the difference between LAF_{90} (i.e. the maximum sound pressure level occurring for 90 % of the measurement period) for the background level and LA_{eq} of an event relating to specific noise level is 5 dB(A) or greater, then the exposure to the noise is deemed to be excessive.

In order for a tone or impulsive element to warrant a penalty it should be clearly noticeable and audible. Situations in which a 5 dB penalty should apply include the following: the noise contains a distinguishable, discrete continuous note (whine, hiss or screech); the noise contains distinct impulses (bangs, clatters or thumps); the noise is irregular enough to attract attention; the level in the 1/3 octave band is 5 dB or more higher than the level in the two adjacent bands and the tonal components are clearly audible.

The EPA Guidance Note advises that at night time, no tonal or impulsive noise from a facility should be clearly audible in a noise sensitive location. Early morning kerb-side deliveries to shops are regarded as being covered by this advice note (EPA, 2007).

The procedures for setting up the microphones to record deliveries and to conduct the experiments in the laboratory are described later in the relevant chapters 3, 4 and 5 and are broadly in accord with BS 4142 (BS, 1997, p.2) and the Environmental Protection Agency *Guidance Note on Noise in Relation to Scheduled Activities* (EPA, 2006, p.8). The parameters and conventions used are defined below. During all the laboratory and field tests described in the later chapters, the B&K microphone was placed at a distance of 3.5 meters from the source and 1.2 meters above ground level. The location of the microphone had regard to the recommendations of free-field conditions as set out by the Environmental Protection Agency (EPA, 2006, p.26)

Decibels (dB)

The decibel is the scale in which sound pressure level is expressed. The decibel (dB) is a dimensionless unit of ratio which is used to express the relationship between a variable quantity and a known reference quantity.

The range of sound pressures of relevance in noise control varies from 2×10^{-5} Pa (Pascals) at the threshold of hearing to normal atmospheric pressure or 1×10^5 Pa (Bell and Bell, 1994).

This range of variation in values is of an inconveniently large order and because the response of the human ear is not directly proportional to pressure, a more manageable logarithmic scale is used. In practice therefore a sound pressure level (SPL) is measured in *decibels* and defined as:

$$SPL = 20 \log_{10} \left(\frac{P_1}{P_0} \right) \quad (2.1)$$

This is not an absolute scale but a comparative scale relating to two different pressures. Pressure P_0 is taken as the pressure at the average threshold of hearing at 1000 Hz or 2×10^{-5} Pa (N/m^2).

A-Weightings

The sound level meters used were calibrated against an A-weighted filter to match the frequency response of the human ear. The A-weighted curve is commonly used to determine the equal loudness contour for the human ear. It has been shown that the decibel readings on the A-scale closely approximate the changes in the sensitivity of the ear to different frequencies, particularly at the lower sound levels (Bell and Bell, 1994, pp.5-6).

Equivalent continuous A-weighted sound pressure $L_{Aeq,T}$

This is the value of the A-weighted sound pressure level in decibels of continuous steady sound that within a specified time interval, T , has the same mean-squared sound pressure as a sound that varies with time. It is given by the following equation:

$$L_{Aeq,T} = 10 \log_{10} \left[\left(\frac{1}{T} \right) \int_{t_1}^{t_2} (p_A^{2(t)} / p_0^2) dt \right] \quad (2.2)$$

where:

$L_{Aeq,T}$ is the equivalent continuous A-weighted sound pressure level determined over a time interval $T = t_2 - t_1$

p_0 is the reference sound pressure ($20 \mu\text{Pa}$)

$p_A(t)$ is the instantaneous A-weighted sound pressure (Pa)

The equivalent continuous A-weighted sound pressure level is quoted to the nearest whole number of decibels.

Specific noise source

This is defined as the noise source under investigation for assessing the likelihood of complaints.

Other terms used are;

Reference time interval, T_r

This is the specified interval over which an equivalent continuous A-weighted sound pressure level is determined.

Specific noise level, L_{Aeq,T_r}

This is the equivalent continuous A-weighted sound pressure level at the assessment position produced by the specific noise source over a given reference interval.

Measurement time interval, T_m

This is the total time interval over which measurements are taken.

Ambient noise

This is the totally encompassing sound in a given situation, at a given time, usually composed of sound from many sources near and far.

Residual Noise

This is the ambient noise remaining at a given position in a given situation at a given time, when the specific noise source is suppressed to a degree that it does not contribute to the ambient noise.

Residual noise level, $L_{Aeq,T}$

This is the equivalent continuous A-weighted sound pressure level of the residual noise during a period of time T in dB with an A weighting.

Background noise level, $L_{AF90,T}$

This is the A-weighted sound pressure level of the residual noise at the assessment position that is exceeded for 90 % of a given time interval, T , measured using time weighting, F , and quoted to the nearest whole number of decibels.

Frequency spectra

The frequency spectra which were downloaded using the B&K software displayed the sound pressure levels in LAF_{max} in dB on the X axis across the frequency range displayed on the Y axis.

The upright “A” bar is the overall LAF_{max} value i.e. the sum of the 1/3 octave bands. The “L” is the LLF_{max} value and is a root mean square parameter integrated over a

period of time. The time period is described by the notation “F” which stands for fast, and equates to a time constant of 0.125 seconds. It is therefore the maximum 0.125 seconds of noise as measured during the measurement period. It has no frequency or “A” weighting i.e. it was taken with linear weighting. These parameters are defined in the *Glossary of Terms*.

Octave Bands

Bruel and Kjaer (2008) defines Octane bands as:

A range of frequencies whose upper frequency limit is twice that of its lower frequency limit. For example, the 1000 hertz octave band contains noise energy at all frequencies from 707 to 1414 hertz. In acoustical measurements, sound pressure level is often measured in octave bands, and the centre frequencies of these bands are defined by ISO and ANSI. The sound pressure level of sound that has been passed through an octave band pass filter is termed the octave band sound pressure level. Similarly, for one-third octave bands, there being three such bands in each octave band.

A sound spectrum is split up into octave bands this is where the octave band is divided into three components called the third octave bands and this gives a more detailed description of the frequency content of the noise. The centre frequencies used are 16 Hz, 31.5 Hz, 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz and 8 kHz (Sharland and Lord, 2005, pp.15-6; Noisemeters.com, 2008).

Adding and Averaging Logarithmic Units

Decibels are logarithmic units which need to be computed and averaged according to the following equation (Environmental Pollution Control Center, 2007) –

$$L_{ave} = 10 \log \frac{1}{n} \left[10^{l_1/10} + 10^{l_2/10} + 10^{l_3/10} + \dots + 10^{l_n/10} \right] \quad (2.3)$$

where:

L_n is the n^{th} sound pressure level reading as measured.

The recorded sound data from the laboratory tests which involved the repeated striking of coated and uncoated metal panels was averaged according to equation 2.3.

The acoustic data arising from the field trials was also averaged.

2.6. Measurement and calculation in environmental noise assessments

In preparation for the laboratory experiments and field trials, the methods behind the measurement of calculations associated with the widely used statistical noise parameters such as LAF_{90} , LA_{eq} and frequency spectra were examined. The limitations and statistical significance of different measurements commonly used were found to be concisely reported in the Institute of Acoustics (Williams, 2008).

2.7. Transmission loss

The transmission loss characteristics of different materials were reviewed to see whether their application would be suitable for application on an HGV trailer unit (Bell and Bell, 1994). The basic property of a partition which determines its effectiveness as a sound insulator is the sound reduction index R , also called the Transmission Loss (TL) in dB.

$$TL = 10 \log \frac{1}{\tau} \quad (2.4)$$

where:

τ is the transmission coefficient averaged over all angles of incidence.

Transmission loss for single skin panels is more commonly expressed as

$$\begin{aligned}
TL &= 20 \log(f) + 20 \log(W) - C \\
\text{where} \\
f &= \text{frequency(Hz)} \\
W &= \text{surfacedensity}(kg / m^2 / cm) \\
C &= 47(kg / m^2 / cm)
\end{aligned}
\tag{2.5}$$

The commonly used transmission loss materials used for acoustical enclosures and isolation barriers are lead, lead vinyl, steel mass concrete and glass (Bell and Bell, 1994). Whilst the attachment of these types of barrier materials are suitable for buildings and for fixed acoustic docking bays, it was felt that they would not be appropriate for a light-weight HGV trailer because of the additional weight and mass involved. The focus was therefore on the application of damping materials as discussed in section 2.7.

2.8. Damping impact noises

Impact noises were found to be a feature of the handling and nesting of steel rollcages during deliveries and for this reason there was a focus on developing damping solutions to attenuate the nuisance caused.

Impact Noise

According to Bell and Bell (1994, chapter 3), impulsive or impact noise is characterized by transient acoustical events of short duration, usually less than 0.5 seconds. The impulsive character can further broken down into two types, types A and B. Type A is described as a rapid rise in sound pressure followed by a uniform decay to a negligible amplitude. Type B or ringing noise, also possesses a rapid rise in sound pressure but the decay is oscillatory in nature. The parameters common to both types A and B which are used to characterize impulsive noise are (1) *peak*: the maximum sound pressure amplitude reached in the event (2) *rise time*: the time from the start of the impulse to when the sound pressure reaches peak value (3) *duration*: the time from the start of the impulse to a specified decay level. In the case of type A, the duration is the time for the peak sound level to decay to the initial level or down to 40dB. For

type B, the duration is usually taken as the time for the envelope of the oscillation to decay to 20dB down.

A distinction is drawn between the two effects of impact noise, the initial impact noise and the subsequent ringing noise. There is a body of literature relating to the theory of impact noises. A key feature of the theory is the distinction between (a) the initial impact noise and (b) the subsequent ringing noise. The initial impact noise produced by impacting bodies on a substrate is due to the high surface accelerations during the contact period while the ringing noise arises from the subsequent free vibration (Richards, Westcott and Jeyapalan, 1979).

Damping

Damping can be described (Bruel and Kjaer, 2008) as combinations of

- (1) the dissipation of energy with time or distance. The term is generally applied to the attenuation of sound in a structure owing to the internal sound-dissipative properties of the structure or to the addition of sound-dissipative materials.
- (2) the action of frictional or dissipative forces on a dynamic system causing the system to lose energy and reduce the amplitude of movement.
- (3) the removal of echoes and reverberation by the use of sound absorbing materials.

Damping mechanisms remove vibrational energy from the transmission path, converting it to heat (Smith and Peters, 1996, Chapter 8.19). Some of the damping occurs within the resonating material and some may occur at joints within the structure of the equipment. Structures which contain riveted or bolted joints tend to be more highly damped than welded one-piece constructions.

The application of damping materials is an effective way of reducing the amplitude of mechanical vibration (Bell and Bell, 1994, Chapter 6.3). Damping treatments are very effective when applied to large areas of thin sheet metal panels because the inherent damping of the steel itself is low. Such treatments are not effective however, when applied to stiff panels and it is recommended that they be stiffened or isolated (Smith and Peters, 1996, Chapter 8).

Interrelated parameters which are used to describe their qualities include (1) the loss factor and (2) the decay rate. The loss factor η is defined in terms of the energy dissipated or the damping to stiffness ratio (Bell and Bell, 1994, Chapter 6.3).

The decay rate Δ is an experimental value obtained by measuring the decay of a freely vibrating sample. The amplitude decay varies exponentially with time and thus is linear if plotted logarithmically. Further the loss factor η is related to the decay rate as follows:

$$\eta = \frac{\Delta}{27.3 f} \quad (2.6)$$

where:

Δ = decay rate (dB/s)

f = decay frequency (Hz)

This equation which relates loss factor η to decay rate Δ , is the one most often used to describe the effects of applying a damping material to a vibrating substrate. The loss factor can be measured from experimental data.

The loss factors for commonly available materials are quoted in the literature (Bell and Bell, 1994, Table 6.3).

2.9. Adjusting the propagation of sound received against distance from a point source

The following procedures were employed to compare the sound measurements carried out in the Netherlands according to the Dutch standards authority TNO (2003) regulations with those conducted in accordance with the procedures recommended by Dublin City Council in accord with the EPA guidelines (2006) which are based on BS4142 (1997). Equations (2.7) to (2.10) apply when adjusting the sound received against distance from a point source.

$$L_r - L_R = 10 \log_{10} \left(\frac{I_r}{I_R} \right) \quad (2.7)$$

$$L_r - L_R = 10 \log_{10} \left(\frac{R^2}{r^2} \right) \quad (2.8)$$

$$L_r - L_R = 20 \log_{10} \left(\frac{R}{r} \right) \quad (2.9)$$

$$L_r - L_R = 20 \log_{10} \left(\frac{7.5}{3.5} \right) = 6.6 \text{ dB} \quad (2.10)$$

where:

- L_r : sound pressure level (dB) at a distance r from the source
- L_R : sound pressure level (dB) at a distance R from the source
- r : a distance from the source (m)
- R : a distance from the source (m)
- I_r : intensity at a distance r from the source
- I_R : intensity at a distance R from the source

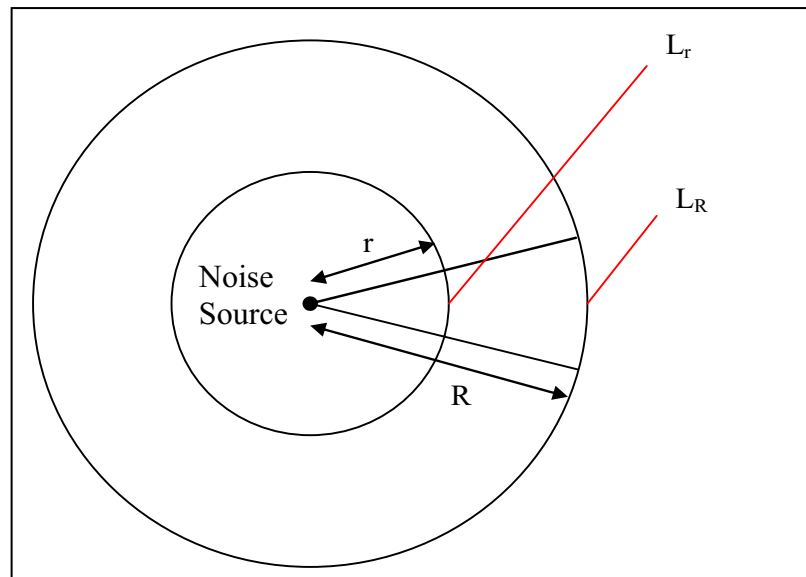


Figure 2.1. Diagram showing how sound intensity decreases in proportion to the distance from a point source (Smith, Peters and Owen, 1996).

In order to convert the Dutch TNO measurements, which were carried out at 7.5m from the noise source to equivalent readings recorded during the Dublin city centre field trials which were measured at a distance of 3.5m from the source in accord with the EPA guidelines for noise, the sum of 6.6 dB should be added to the corresponding

TNO measurements, as shown by equation (2.10) (EPA, 2006). Figure 2.1 shows how sound intensity decreases in proportion to the distance from a point source.

2.10. Materials selection

In order to decide which category of acoustic materials might be the most suitable for application to the HGV and the related ancillaries, a literature review was completed in order to compare the characteristics of the different types of material available and to match these to the high frequency sounds generated during deliveries.

As described in chapter 4, acoustic materials may be divided into three categories namely absorbing materials, barrier materials and damping materials. Absorbing materials are resistive in nature and may be fibrous, porous or reactive resonators. Classic examples of resistive materials are fibrous glass, mineral wools, felt and polyurethane type foams. Barrier materials are characterised by dense mass and have a high degree of internal damping or *limpness* of which sheet lead is the best example. The sound barrier properties of materials are governed by mass, stiffness and damping. Damping materials are usually thin adhesive sheets or coatings of plastic polymers, metal epoxy, or glue which can be adhered to sheet metal panels and machine parts. When these coatings are applied, the response of an impact blow to a metal panel is a dull thud rather than a ring.

Because of the type of events and sudden impacts that generate noise during deliveries and due to the relative ease with which damping materials can be retro-fitted to vehicle parts, it was decided to focus on the application of damping materials and coatings. Following an examination of how an HGV trailer is constructed and having observed the location of the resonating surfaces that suffer repeated impacts, it was decided to apply damping materials in the form of coatings to these surfaces. These surfaces were seen to comprise the aluminium floor and kick-walls of the HGV trailer and the surface of the tail-lift. The restricted dimensions and spaces available in a standard HGV trailer would not permit the installation of bulky absorption or barrier materials and therefore the thinner damping materials would be much easier to fit.

Viscoelastic damping strips and rubber bands were selected for application to the steel roll-cages. It was found that the performance of different types of commercially available acoustic materials was published by independent laboratories according to ASTM standards and that this information was included in the sales and technical literature provided by the different suppliers (ASTM 2794, 2007). Because high frequency noise was found to be characteristic of the manipulation of roll-cages it was decided to select those materials that would attenuate the higher frequencies.

2.11. The application of damping materials

In order to understand the fundamentals of mechanical vibrations in relation to noise controls and to help select the most appropriate damping solutions, several texts and guidebooks were consulted (Hussey 1983, pp.248-64 and Mulholland and Attenborough 1981). These were found to complement the textbooks noted in section 2.5 (Bell and Bell 1994 and Smith, Peters and Owen 1996). The practical applications of acoustic theory were found to be comprehensively described by Sharland (2005) in the Flakt Woods Practical Guide to Noise Control and in the Singapore Ministry of Manpower Guidebook on Noise Control (Singapore Government, 2008) which aims to improve working conditions for individuals in noisy work environments.

According to Bell, damping is best described as the dissipation of mechanical energy associated with vibration. The noise reduction capability of applying damping materials is that noise is not so readily re-radiated in the form of airborne sound or conducted along structurally, because the amplitude of the mechanical vibration is effectively reduced. With respect to the best thickness to apply, a thin coating on sheet metal, one half of the metal thickness or 10% by weight, will eliminate the “ring” from shock excitation according to Bell (Bell and Bell, 1994, pp.221-225).

The damping treatment involves applying a highly damped layer, often of viscoelastic material, next to the vibrating sheet metal. The layer is made to vibrate following the motion of the base layer and much of its vibrational energy is abstracted by the damping process. Mastic treatments can be sprayed or painted directly on to a sheet

metal base layer or can also be applied as an acoustic sheet which is attached with adhesives.

There are two commonly used damping treatments;(1) homogenous or free-layer damping, also referred to as surface damping and (2) constrained layer damping which involves sandwiching a layer of viscoelastic material between the structure being damped and an outer constraining layer (Singapore Government, 2008, pp.70-3).

Homogeneous damping is a single treatment in which rubbery, tarry or plastic based material or coating is sprayed on, brushed on or adhesively bonded (in sheet form) to the panel surface. The new acoustic coating described in chapter 4 falls into this category.

Constrained layer damping involves sandwiching a thin layer of viscoelastic material between the structure being damped and an outer constraining layer. Commercial “constrained” sandwich materials having a constraining outer layer are available in sheet form. The constraining layer creates shear strain in the damping layer, helping to make the sandwich material more efficient. To be effective, damping treatments need be applied only to a part, usually one-third, of a panel surface (Smith, Peters and Owen, 1996, Chapter 8). The purpose is to resist extension and compression of the viscoelastic material, so that significant shear stresses are induced. These stresses in turn cause dissipation of the vibratory energy (Singapore Government, 2008, pp.71-2).

In order to compare the effectiveness of a commercially available “constrained” damping material with the new “brushed-on” homogeneous acoustic coating under development, an adhesive viscoelastic tape was selected and sourced from a supplier in the UK (Ygro, 2006). The constraining layer comprised a thin metal foil with a pressure sensitive bonding adhesive on one side. This adhesive then became the viscoelastic damping layer. These “constrained layer” damping products are, according to Bell, popular for application to flat and to curved surfaces as used in aircraft and in the heating and air conditioning industries (Bell and Bell, 1994, p.232).

In addition to the pendulum impact tests mentioned earlier, the damping effectiveness of the new acoustic coating on aluminium and mild steel panels was measured by

recording the decay rates and reverberation times of the sound impacts caused by the striking of the panels and by using a microphone attached to an oscilloscope by means of a pre-amplifier. The experiment was designed to confirm the damping effectiveness of the damping materials which were indicated by the earlier pendulum tests.

As discussed in section 2.3, the damping of the HGV trailer floor and the tail-gate platform (as described in chapter 4) was achieved by the application of a new acoustic coating while the steel roll-cages were damped by means of retro-fitting and bonding rubber pieces and viscoelastic strips to the vibrating parts in the form of a “hush-kit” (as described in chapter 5).

In the case of damping the noise generated by the roll-cages however, research reported in the Journal of Applied Acoustics (Jaouen, Renault and Deverge, 2007) suggests that injecting the tubular hollow frames with melamine porous foam might be worth investigating. This is a recommendation for future research which is made in chapter 6.

In the case of the aluminium and metal flooring panels of an HGV trailer and tail-gate, a further recommendation is made in chapter 6, that consideration is given to perforating the panels in order to change their natural frequencies and to reduce their effectiveness for radiating sound (Singapore Government, 2008, p.75).

2.12. Analytical software

Software was sourced to analyse the acoustic data generated by the field trials and by the experiments conducted in the laboratory. Access to a Bruel and Kjaer “Evaluator” software package was arranged courtesy of Dublin City Council. “Evaluator” is a programme for storing, retrieving and for converting measurement data from Bruel and Kjaer sound level meters (Bruel and Kjaer, February 2007).

There are many ways of processing the data, each designed to allow the results to be presented in the desired format. The data is initially recorded on a hard disk and inserted into “project” folders. A “project” is a collection of measurement data,

calculations and results files. Results files are collections of measurements and calculation files that are operated upon algorithms according to national or international standards. Measured parameters such as LA_{eq} , LAF_{Max} are represented by curves, the x-axis represents time, the y-axis the acoustic levels.

In the case of the field trials and laboratory experiments, the data was manipulated to give a graphic recording of LA_{eq} and LAF_{max} levels and to identify the frequencies associated with the specific peak events. The software made it possible to zoom in and to magnify the acoustic data recorded during time intervals of one second when the particular events occurred. These peak events were identified by examining the graphic and time records made during the field trials and during laboratory testing and frequency “spectra” were developed for these peak events.

2.13. Setting Boundary Conditions for the Experiments

Boundary conditions were established for the different tests carried out in the laboratory in order to ensure repeatability. The field trials of deliveries to shops were as mentioned earlier, carried out in accordance with the relevant British and ISO standards (BS 4142, ISO 1996).

The falling weight tube tests on small coated substrates were carried out on similarly sized aluminium and steel panels using a standard piece of laboratory equipment as described in chapter 4. The falling weight and pendulum tests that were conducted on larger 1 m² aluminium and steel panels were carried out on specially designed equipment as described in chapter 4. The thickness and patterns of the panels tested were noted.

The sound damping effects of securing the panels on the pendulum apparatus with different torques was also evaluated in order to ensure consistency throughout the testing.

The rotating carousel apparatus facilitated carefully controlled experimental conditions whereby the parameters such as the speed of the carousel, the path transited

by the wheels of the roll-cages under test and the types of panels affixed to the carousel platform were all carefully monitored.

2.14. Perceptions of noise and psychoacoustic considerations

How different noises are perceived by different populations has merited investigation by the Acoustics Research centre at the University of Salford. Psychoacoustic experiments have indicated a general public intolerance for noise created by events such as squeaky trolleys and scraping sounds. These are peak sounds which are very similar to those experienced during deliveries to stores (Cox TJ, 2007). The criticism is also made that the conventional noise mapping procedures neglects to effectively measure peak impact sounds to adequately reflect the acoustic environment and to record the peak disturbances caused by traffic related events which would include deliveries (Ng CH, Tang SK, 2007).

In order to explore the public perceptions of night delivery disturbances and as a complementary project to this particular research, DIT has initiated a psychoacoustic survey of 600 affected residents in selected locations in Dublin city centre. The results will be reported in late 2008 as a follow on to the Innovation Partnership project entitled "*Low Noise Solutions for Night Deliveries*" (Byrne R, Finlay H and Grimes J, 2007).

2.15. To conclude

A methodology was developed to produce research results that could confirm the hypothesis. This was based on a literature review of the theory of sound and vibration control and a survey of best practice for developing and for conducting the different actions and test procedures proposed. While the initial field trials involved measuring absolute values for the peak sounds caused by deliveries on the streets, much of the other trials involved comparative tests of the application of different acoustic materials to a variety of substrates for which generating data for relative values were deemed to be appropriate. Much use was made of adapting the BS 4142 procedures

for measuring noise. The development of special test rigs, namely the portable pendulum and falling weight rigs and the hydraulically driven carousel assembly were considered to be unique to the project.

CHAPTER 3. ANALYSIS OF DISTURBANCE CAUSED BY DELIVERIES

3.0. Introduction

As part of the Innovation Partnership project a series of field trials were carried out of kerb-side deliveries to city centre stores in order to assess the disturbance caused and to identify the particular events that caused the peak noises (Byrne, Finlay and Grimes 2007). Early morning deliveries before the 7 a.m. curfew by large five axle HGVs to eight selected stores were monitored and these deliveries included both ambient and chilled foodstuffs. For the purposes of this research the focus was on the delivery of ambient goods to four particular stores because the configuration of a multi-temperature HGV, which includes a refrigeration unit, is noisier than that of an ambient HGV.

This chapter analyses the acoustic data which was collected at the different stores and describes the methodology used. The stores selected were located within the city centre area, bounded by the canal cordon and represented different street-scapes and topographies. A supermarket and convenience store grocery (Musgrave SuperValu Centra Group) chain kindly provided details of their delivery schedules to their chain of supermarkets and convenience stores and facilitated the conduct of the field trials.

As described in chapter 2, British Standard 4142 procedures were applied to evaluate the disturbances caused and courtesy of Dublin City Council, two Bruel and Kjaer Modular Precision Sound Analyser Type 2260 meters were made available for field trials (British Standards, 1997). The field trials were carried out during March 2006 by a team of four researchers and the results relating to each particular store were reported in confidence to the Musgrave management in July 2006. The location of the four shops reported on is not disclosed for reasons of commercial sensitivity.

3.1. Methodology

In accord with the procedures employed by Dublin City Council which, as mentioned in Chapter 2.5.1, are an adaptation of British Standard 4142 (1997), both the **‘background noise level’** (in the absence of a delivery) and the **‘specific noise level’** (noise in the presence of a delivery operation and in the absence of background noise) was recorded at each selected premises.

This was done by positioning a Bruel and Kjaer meter at a height of 1.2 meters from the ground and at a distance of 3.5 meters from the expected noise source (e.g. the back door of the HGV trailer unit). The background sound was recorded before the arrival of the HGV delivery and the specific noise levels were recorded during the actual delivery operation from the same position.

In comparing the readings recorded in Dublin with those recorded by the Dutch “PEAK” programme described in chapter 2, it was noted that the distances at which the noise meters were positioned from the noise sources were substantially greater in the Netherlands, 3.5 meters in Ireland (EPA, 2006, p.8) and 7.5 meters in the Netherlands in accordance with TNO procedures (TNO, 2003). The readings recorded in Dublin should therefore be adjusted to give 6.62 dB(A) higher readings than the comparable Dutch readings for similar activities. The calculation is described in Chapter 2 using equations (2.7) to (2.10) (Smith, Peters and Owen, 1996, chapter 5).

The stores and their locations were selected in consultation with the Musgrave management and with Dublin City Council so as to give a representative sample of different street-scapes (i.e. wide streets and canyon streets). It was observed that different HGV articulated trucks were rostered to deliver to the different stores and that the newly registered '06 DAF five axle vehicles tended to be quieter than the older vehicles.

As described in chapter 2, sound pressures can be measured by different parameters, namely by LAF_{max} or LA_{eq} . LAF_{max} measures the maximum sound pressure level over short periods of time. LA_{eq} calculates the equivalent average of fluctuating sound pressures over a given period of time. Definitions of the various parameters used can

be found in the glossary of terms. The accepted norm according to BS 4142, for measuring the disturbance caused by a particular event is to compare the LA_{eq} measured during that particular event with the LAF_{max} for the preceding background period. The authorities generally perceive events adding 6 dB(A) or more to the background noise levels as causing serious annoyance to residents in the vicinity of the noise source. In other words, if the difference between ² LAF_{90} for the background level, and the LA_{eq} of an event relating to specific noise level is 6 dB(A) or greater, then the exposure to the noise is deemed to be excessive (British Standards, 1997).

3.1.1. Background noise level, $LAF_{90,T}$

The A-weighted sound pressure level of the residual noise at the assessment position that is exceeded for 90 % of a given time interval, T , measured using time weighting, F , and quoted to the nearest whole number of decibels.

Because high and sudden impact and “pure tone” frequencies (refer to the glossary of terms) are known to cause most discomfort, the frequencies relating to particular events were identified and evaluated by developing spectras for those peak events (Bell and Bell, 1994). The B&K “Evaluator” software used for this analysis is mentioned in chapter 2.

3.2. Research results and analysis

3.2.1. Specific noise verses background noise

A sample size of eight stores was selected at which early morning deliveries occur and these deliveries included both ambient and chilled goods, but because the focus of this investigation is on deliveries by ambient rather than multi-temperature HGV units, the

² the background noise level, LAF_{90} is the A-weighted sound pressure level of the residual noise at the assessment position that is exceeded for 90% of a given time interval, measured using fast time weighting, F , and quoted to the nearest whole number of decibels (Bruel and Kjaer, 2008)

data relating to the four particular stores at which such goods were delivered is examined in this chapter.

The procedure involved measuring the **background noise level** for a period of from 5 to 10 minutes in order to record the noise sensitivity of each neighbourhood. For example some streets were found to have a higher level of by-pass traffic flows than others. The less trafficked wider streets were characterised as being in a low-noise area while more reverberation occurred in narrow “canyon” type streets when traffic passed by.

Specific noise levels were then measured for the duration or “dwell time” of each delivery operation, i.e. from the arrival of the HGV to its departure from the kerb-side.

The results of the average background noise levels and for the overall specific noise levels recorded at the four different stores, A B C and D, are given below in Table 3.1. LA_{eq} values are given for time duration of each delivery operation while LAF_{90} values are given for the time duration which the background noise is measured. The use of the parameter LAF_{90} enabled untypical noises to be discounted.

Table 3.1. Average specific noise compared with the background noise levels

Store	Overall Specific Noise (LA_{eq}) (dB(A))	Overall Background Noise (LAF_{90}) (dB(A))	Overall Difference (dB(A))
A	72.8	52.2	20.6
B	65.5	50.8	14.7
C	68.4	³ n/a	n/a
D	71.2	55.1	16.1

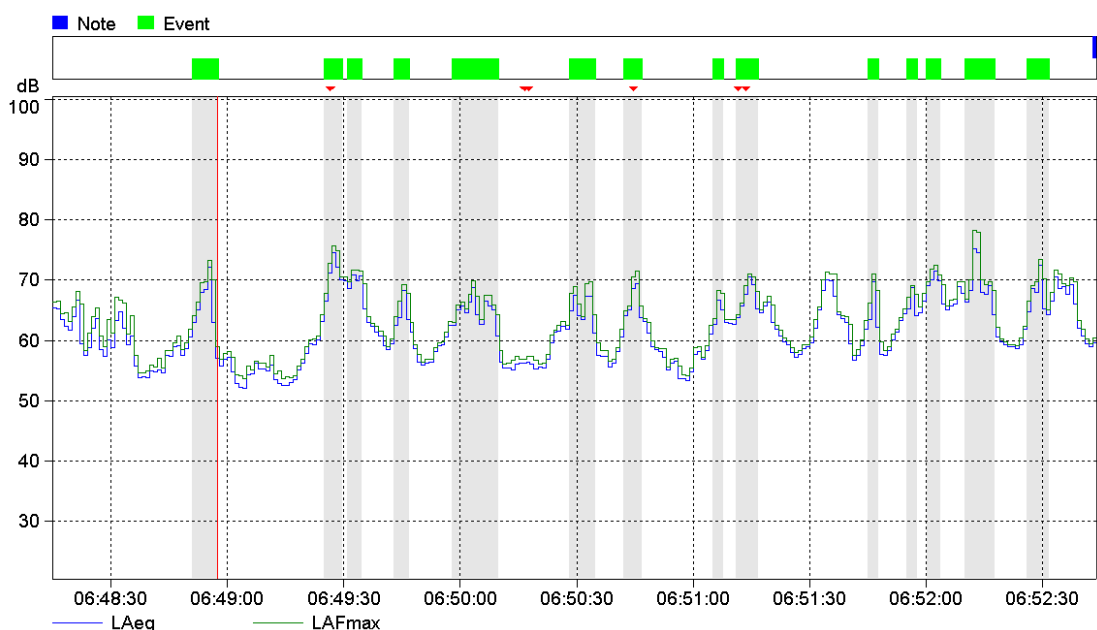
It can be seen from Table 3.1 that the deliveries added significantly in all cases to the background noise ranging from 14.7 dB(A) to 20.6dB(A) for the different stores. There were also differences between the levels of disturbances at the different locations. This can be explained by the fact that store B was situated in a wide street

³ In the case of store C Bruel and Kjaer software was not programmed to upload LAF_{90} for the background noise.

with low buildings while store A could be described as being sited in a “canyon” street with tall apartment buildings and with busy by-pass traffic.

As an example, the situation at store D recorded on the morning of 22nd June 2006 is analysed in the following figures; the data for the other three premises is described in Appendix I.0. A night vision camera was used to record the graphic data to relate the peak sounds to the relevant events and activities taking place on the streets.

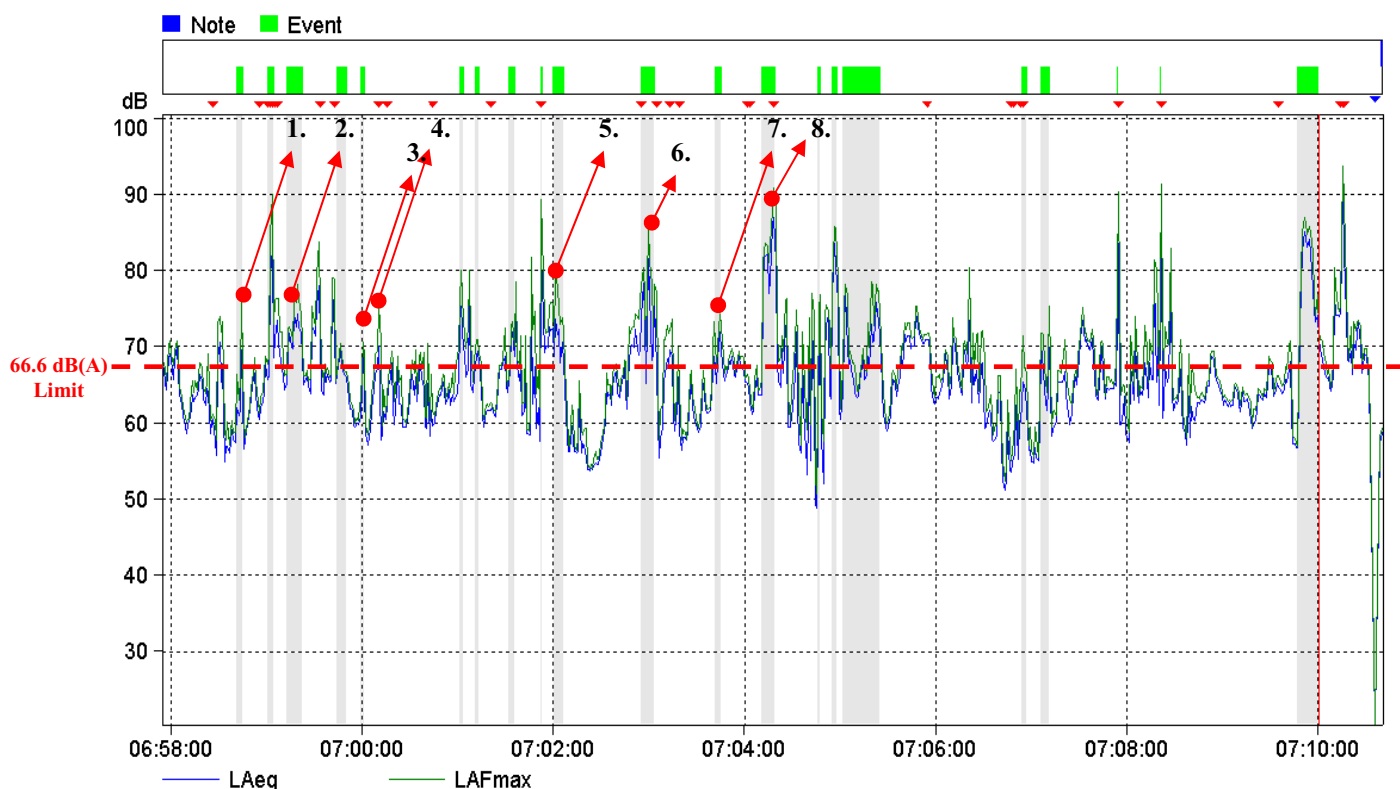
In the case of store D the background noise was monitored for a period of 6 minutes 48 seconds as shown in Figure 3.1. The peaks related to by-pass traffic (i.e. cars, buses, vans and trucks) as recorded in the accompanying data log. The weather conditions were noted as was the topography of the area. The temperature was 10°C, the conditions were dry, relatively windy (although wind speeds were not as high as to affect the results) and in a relatively wide street located in a mixed residential and retail part of the city centre. By-pass traffic noise was caused by vans and taxis. The background noise was measured beginning at 6.08am and it was noted that peaks at the beginning of the monitoring period were due to the noise of the HGV tractor unit engine which was turned off some minutes before the shop opened and the actual delivery began. The delivery began at 6.48 a.m., the dwell time was 12 minutes 46 seconds and started at 06:58 and involved the unloading of batches of loaded rollcages and the return of empty rollcages and their folding and storage within the HGV trailer unit.



Name	Start time	End time	Duration	LAeq [dB]	LAF90 [dB]	LAFmax [dB]	Remarks
Total	22/06/2006 06:48:15	22/06/2006 06:52:44	0:04:29	64.7	55.1	78.2	
Unmarked	22/06/2006 06:48:15	22/06/2006 06:52:43	0:03:11	61.9	54.5	71.5	
(All) Note	22/06/2006 06:52:43	22/06/2006 06:52:44	0:00:01	59.5	59.1	60.4	
(All) Event	22/06/2006 06:48:51	22/06/2006 06:52:32	0:01:17	68.1	62.5	78.2	
Note	22/06/2006 06:52:43	22/06/2006 06:52:44	0:00:01	59.5	59.1	60.4	Weather: dry, 10C, high wind speed
Event	22/06/2006 06:48:51	22/06/2006 06:48:58	0:00:07	67.3	57.5	73.3	Passing traffic
Event	22/06/2006 06:49:25	22/06/2006 06:49:30	0:00:05	71.6	65.5	75.6	passing bus
Event	22/06/2006 06:49:31	22/06/2006 06:49:35	0:00:04	70.1	68.3	71.6	passing car
Event	22/06/2006 06:49:43	22/06/2006 06:49:47	0:00:04	65.1	61.7	69.3	passing car
Event	22/06/2006 06:49:58	22/06/2006 06:50:10	0:00:12	65.3	62.3	69.8	3 passing cars
Event	22/06/2006 06:50:28	22/06/2006 06:50:35	0:00:07	65.6	62.1	69.6	2 passing cars
Event	22/06/2006 06:50:42	22/06/2006 06:50:47	0:00:05	66.8	63.5	71.4	passing car
Event	22/06/2006 06:51:05	22/06/2006 06:51:08	0:00:03	65.1	62.3	68.2	passing car
Event	22/06/2006 06:51:11	22/06/2006 06:51:17	0:00:06	67.6	63.7	71.1	2 passing cars
Event	22/06/2006 06:51:45	22/06/2006 06:51:48	0:00:03	66.4	60.9	70.9	passing car
Event	22/06/2006 06:51:55	22/06/2006 06:51:58	0:00:03	66.5	63.7	69.1	passing car
Event	22/06/2006 06:52:00	22/06/2006 06:52:04	0:00:04	70.2	68.5	72.4	3 passing cars
Event	22/06/2006 06:52:10	22/06/2006 06:52:18	0:00:08	70.7	66.0	78.2	2 passing cars
Event	22/06/2006 06:52:26	22/06/2006 06:52:32	0:00:06	68.2	63.2	73.4	3 passing cars

Figure 3.1. Background noise and data log at store D, LA_{eq} measured at 1second intervals

The actual delivery operation which followed is recorded in Figure 3.2 and the specific events that generated the peak sounds can be identified from the accompanying data log.



	Name	Start time	End time	Duration	LAeq [dB]	LAF90 [dB]	LAFmax [dB]	Remarks
	Total	22/06/2006 06:57:55	22/06/2006 07:10:41	0:12:46	71.2	57.6	93.8	
	Unmarked	22/06/2006 06:57:55	22/06/2006 07:10:40	0:10:38	68.1	57.2	93.8	
	(All) Note	22/06/2006 07:10:40	22/06/2006 07:10:41	0:00:01	58.8	58.4	59.4	
	(All) Event	22/06/2006 06:58:41	22/06/2006 07:10:01	0:02:07	76.8	63.1	91.2	
	Note	22/06/2006 07:10:40	22/06/2006 07:10:41	0:00:01	58.8	58.4	59.4	Conditions: dry, 10 degrees C, high wind speeds
1.	Event	22/06/2006 06:58:41	22/06/2006 06:58:48	0:00:05	64.5	56.1	75.8	Full roll cages moving onto tail lift from truck body
	Event	22/06/2006 06:59:01	22/06/2006 06:59:05	0:00:04	78.7	63.9	89.9	Lugs folded down with full cages moving along pavement
2.	Event	22/06/2006 06:59:13	22/06/2006 06:59:23	0:00:10	71.9	68.6	78.2	Full roll cage moving along pavement
	Event	22/06/2006 06:59:44	22/06/2006 06:59:51	0:00:07	67.4	65.8	70.4	Tail lift moving upwards with no roll cages
3.	Event	22/06/2006 06:59:59	22/06/2006 07:00:02	0:00:03	65.8	60.2	70.6	Full roll cages moving from trailer body onto tail lift
4.	Event	22/06/2006 07:01:01	22/06/2006 07:01:04	0:00:03	73.0	69.0	80.1	Full roll cages moving from tail lift onto pavement
	Event	22/06/2006 07:01:11	22/06/2006 07:01:14	0:00:03	68.7	67.0	70.9	Full roll cage moving along pavement to store & passing traffic
	Event	22/06/2006 07:01:32	22/06/2006 07:01:37	0:00:05	71.2	66.7	78.5	Passing bus
	Event	22/06/2006 07:01:52	22/06/2006 07:01:54	0:00:02	79.7	55.0	89.2	Door of 'pay&display' box closing
5.	Event	22/06/2006 07:02:00	22/06/2006 07:02:07	0:00:07	70.8	66.1	79.9	Full roll cages moving along pavement to store
6.	Event	22/06/2006 07:02:55	22/06/2006 07:03:04	0:00:09	76.1	64.8	86.0	Empty roll cages moving from footpath onto tail lift
7.	Event	22/06/2006 07:03:42	22/06/2006 07:03:46	0:00:04	69.9	64.7	74.4	Full roll cage moving along pavement to store
8.	Event	22/06/2006 07:04:11	22/06/2006 07:04:20	0:00:09	82.7	75.7	90.9	Empty roll cages moving along pavement to truck
	Event	22/06/2006 07:04:46	22/06/2006 07:04:48	0:00:02	71.1	49.5	76.8	Securing of empty roll cages on tail lift
	Event	22/06/2006 07:04:55	22/06/2006 07:04:59	0:00:04	80.3	75.2	85.8	Securing of empty roll cages on tail lift
	Event	22/06/2006 07:05:02	22/06/2006 07:05:28	0:00:24	70.7	64.0	78.5	Tail lift moving upwards with empty roll cages
	Event	22/06/2006 07:06:54	22/06/2006 07:06:58	0:00:04	64.3	58.4	71.3	Noise from inside the trailer body (cages moving around)
	Event	22/06/2006 07:07:06	22/06/2006 07:07:12	0:00:06	67.4	60.4	75.3	Noise from inside the trailer body (cages moving around)
	Event	22/06/2006 07:07:54	22/06/2006 07:07:55	0:00:01	83.6	60.2	90.2	Folding of tail lift lugs
	Event	22/06/2006 07:08:21	22/06/2006 07:08:22	0:00:01	85.8	70.0	91.2	Folding of tail lift lugs
	Event	22/06/2006 07:09:47	22/06/2006 07:10:01	0:00:14	80.6	66.2	86.9	Truck driven away

Figure 3.2. Specific noise at store D and data log, LA_{eq} measured at 1second intervals. The peaks numbered 1 to 8 relate to the remarks in the accompanying datalog.

It can be seen from Figure 3.2 that there was a significant increase in the intensity of the peak events that occurred during the actual delivery operation compared with the background peaks shown earlier in Figure 3.1. and that the events highlighted in Figure 3.2 related to the handling and passage of the roll-cages. The peaks numbered 1 to 8 relate to the data-log accompanying Figure 3.2 and are appropriately tagged.

When comparing the measurements taken in Dublin with measurements recorded in the Netherlands, the measurements recorded by DIT should be adjusted by adding 6.6 dB(A) to the peak readings recorded by TNO for similar events in order to correct for the closer positioning of the sound meter in accord with BS 4142 compared with the TNO procedure. If the night time noise limits which apply to Dutch cities were to be applied to Dublin, the peak limit for delivery operations would be LA_{eq} 66.6 dB(A). The 66.6 dB(A) limit is illustrated in Figure 3.2. The challenge for deliveries in

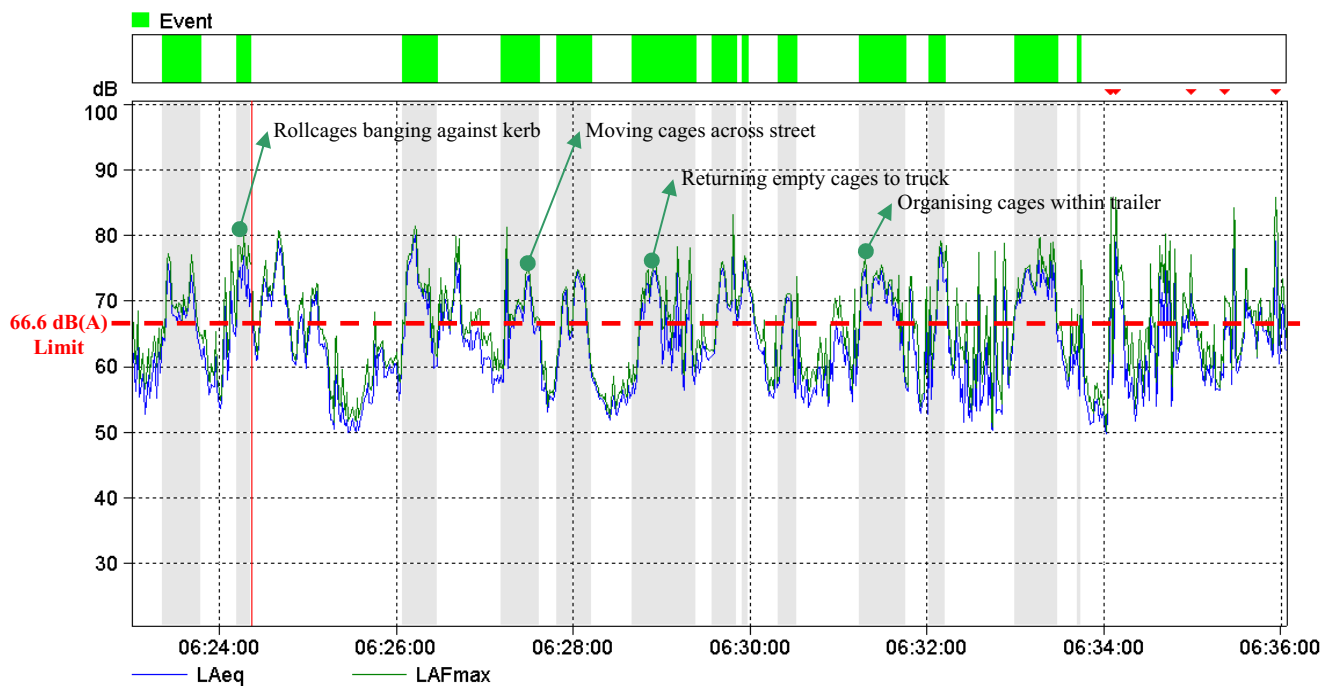
Dublin is therefore to attenuate the peak sounds created by the roll-cages to within peak limits approaching LA_{eq} 66.6 dB(A) measured every 1 second.

3.2.2. Identification of specific noise events

The measurements of both the sound pressure levels of the peak events relating to the four ambient deliveries to stores A, B, C and D were analysed and these are described in detail in Appendix I.0. Corresponding frequency spectras for selected events are illustrated in Appendix I.1.

The spectra are taken by focusing on a particular event and visually represent how the sound behaves at specific frequencies across the sound range. This is explained in further detail in the methodology chapter (chapter 2).

In order to examine the peak sounds caused by the manipulation of the rollcages the delivery to store C was selected as a typical example. The events which comprise the delivery to store C on 10th March 2006 are illustrated in Figure 3.3 with the accompanying log-data.



Name	Start time	End time	Duration	LAeq [dB]	LAFmax [dB]	Remarks
Total	10/03/2006 06:23:01	10/03/2006 06:36:04	0:13:03	68.4	85.7	
Unmarked	10/03/2006 06:23:01	10/03/2006 06:36:04	0:08:35	65.9	85.7	
(All) Event	10/03/2006 06:23:21	10/03/2006 06:33:45	0:04:28	71.0	83.2	
Event	10/03/2006 06:23:21	10/03/2006 06:23:48	0:00:27	69.4	77.1	rollcages crossing road
Event	10/03/2006 06:24:12	10/03/2006 06:24:22	0:00:10	73.4	79.8	Rollcages banging against kerb
Event	10/03/2006 06:26:04	10/03/2006 06:26:28	0:00:24	73.4	81.3	tailgate going up
Event	10/03/2006 06:27:11	10/03/2006 06:27:38	0:00:27	69.1	81.2	tailgate down with full rolcages
Event	10/03/2006 06:27:49	10/03/2006 06:28:13	0:00:24	69.7	74.7	moving cages across street
Event	10/03/2006 06:28:40	10/03/2006 06:29:24	0:00:44	68.9	78.1	returning empty cages to truck
Event	10/03/2006 06:29:34	10/03/2006 06:29:51	0:00:17	71.7	83.2	empty cages onto tailgate
Event	10/03/2006 06:29:54	10/03/2006 06:29:59	0:00:05	74.0	76.8	tailgate going up & lugs folded
Event	10/03/2006 06:30:19	10/03/2006 06:30:32	0:00:13	67.5	73.8	empty cages moved to back of trailer
Event	10/03/2006 06:31:14	10/03/2006 06:31:46	0:00:32	71.0	76.5	organising cages within trailer
Event	10/03/2006 06:32:01	10/03/2006 06:32:13	0:00:12	72.7	79.1	organising cages within trailer
Event	10/03/2006 06:32:59	10/03/2006 06:33:29	0:00:30	72.6	79.6	closing doors & folding tailgate underneath
Event	10/03/2006 06:33:42	10/03/2006 06:33:45	0:00:03	65.4	76.1	starting engine & driving off

Figure 3.3. Specific noise at store C and data log, LAeq measured at 1second intervals

The peak sounds caused by the manipulation of the roll-cages inside the trailer body at store D as described in Figure 3.3 are highlighted in Table 3.2.

Table 3.2. Noise generated by roll-cages inside the HGV

Event	Duration	LAeq (dB(A))	LAF _{max} (dB(A))
Manipulation of roll-cages inside the HGV	12 seconds	72.7	79.1

The noise emanating from the trailer body was measured by positioning the noise meter at a distance of 3.5 meters from the rear of the trailer. A LAF_{max} value of 79.1 dB(A) with frequencies at the mid range of 1,000 Hz was recorded at store C caused by the movement of full roll cages within the body as shown in the data log described in Table 3.2 and on the spectra for this event illustrated in Figure 3.3.

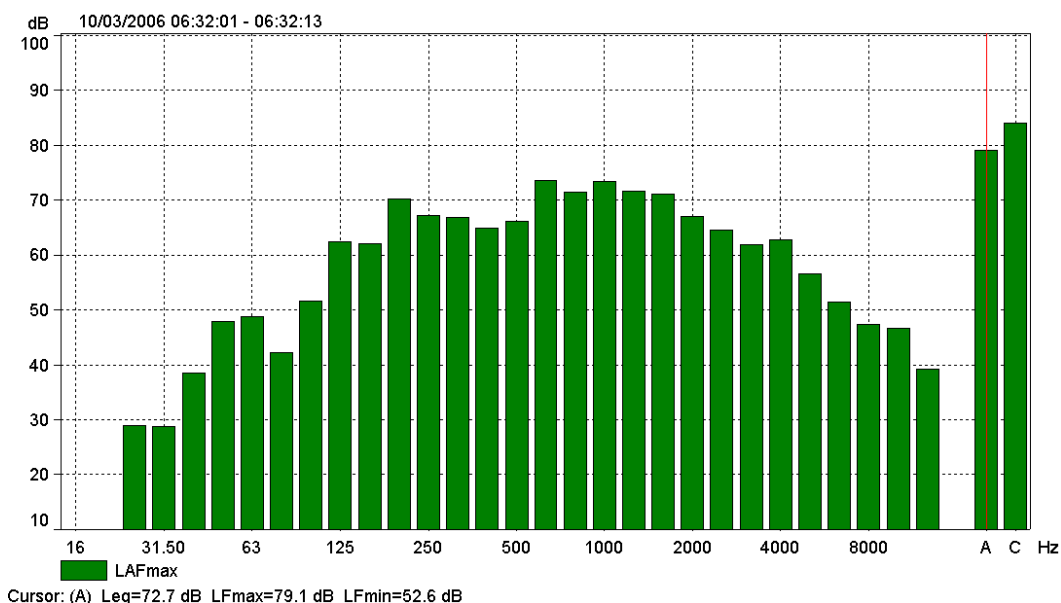


Figure 3.4. Frequency spectra for the movement of full roll cages within the trailer body at store C

The peak noise generated at store C by the manipulation of a loaded cage from the rear of the HGV trailer onto the tail-lift and from the tail-lift across the kerb and pavement into the store is described in Table 3.3.

Table 3.3. Noise of a loaded roll cage exiting from the HGV across the pavement to store C

Event	Duration (seconds)	LA _{eq} (dB(A))	LAF _{max} (dB(A))
Moving from trailer body onto tail lift	0:00:57	68.6	80.7
Moving from tail lift onto pavement	0:00:11	74.6	85.3
Mounting the kerb	0:00:10	73.4	79.8
Moving along pavement to store	0:01:48	70.6	85.2

This can be compared with the noise caused by the handling of an empty roll-cage at store C which is shown in Table 3.4.

Table 3.4. Noise of an empty roll cage being returned from store C to HGV

Event	Duration (seconds)	LA _{eq} (dB(A))	LAF _{max} (dB(A))
Moving along pavement from store to HGV	0:00:09	82.7	90.9
Moving from pavement onto tail lift	0:00:17	71.7	83.2
Moving from tail lift into trailer body	0:00:11	73.4	82.8

The passage of the roll cages, whether full or empty, caused high peak sounds ranging from 80.7 to 90.9 LAF_{max} dB(A) as shown in Tables 3 and 4 above.

The movement of a full cage from the tail lift onto the pavement produced an LA_{eq} of 74.6 dB(A) and LAF_{max} of 85.3 dB(A). The transiting of the pavement produced a sound evenly spread across all the frequency ranges as can be seen in Figure 3.4.

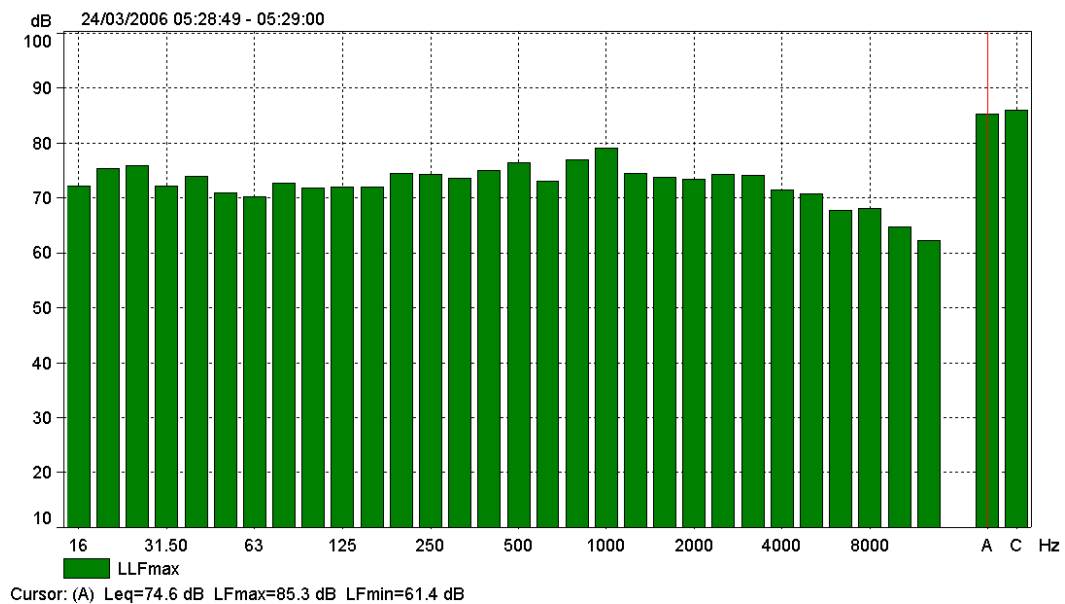


Figure 3.5. Frequency spectra for movement of a full roll cage from the tail lift onto pavement

In contrast, the return movement of empty roll cages from the pavement to the tail lift produced an LA_{eq} of 76.3 dB(A) and LAF_{max} of 90.3 dB(A) in the relatively higher range of 1,000 Hz as shown in Figure 3.5.

An analysis of the frequency spectras for the peak events showed that these specific events were characterised by unique “signature frequencies”. The characteristic frequencies are presented in Table 3.5.

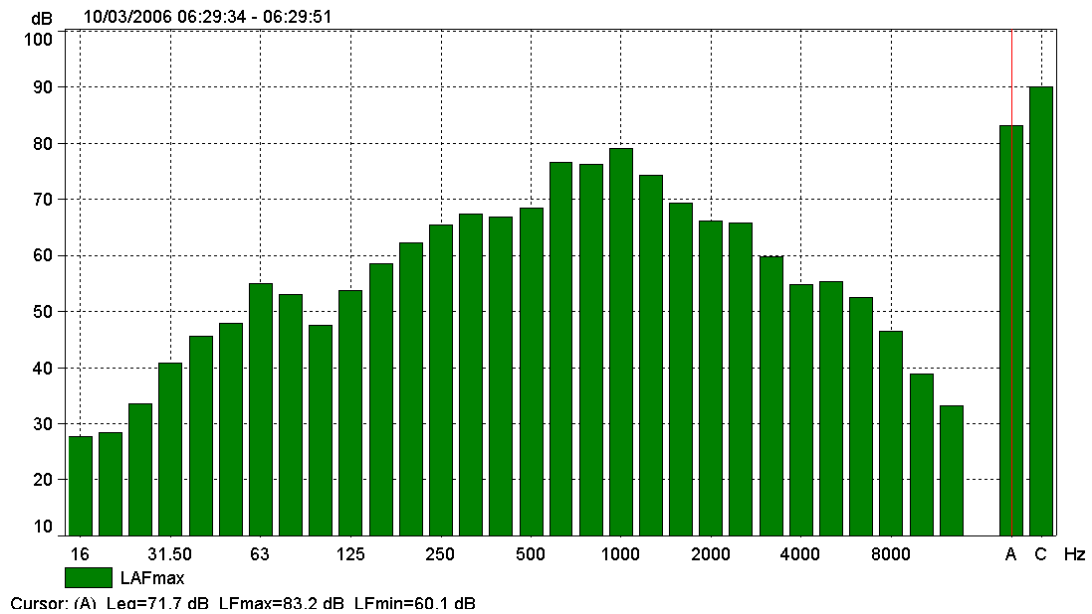


Figure 3.6. Frequency spectra for movement of an empty roll cage from pavement onto tail lift

Table 3.5. Characteristic signature frequencies for particular peak events

Product	Event	Characteristic Frequencies
Trailer body	– Manipulation by driver of ancillaries inside	- 1,000 to 2,000 Hz
Roll cage (full)	<ul style="list-style-type: none"> – Moving from trailer body onto tail lift – Moving from tail lift onto pavement – Mounting the kerb – Moving along pavement (to store) 	<ul style="list-style-type: none"> - none - none - 315 Hz, 500 Hz - 63 Hz
Roll cage (empty)	<ul style="list-style-type: none"> – Moving along pavement (towards HGV) – Moving from pavement onto tail lift – Moving from tail lift into trailer body 	<ul style="list-style-type: none"> - none - 1,000 to 1,600 Hz - 1,000 Hz

This analysis indicated that the challenge was to attenuate the high frequency peak noises caused by the manipulation of the roll-cages inside the HGV trailer unit, across the tail lift and onto the pavement and over the kerb-sides to the stores. The empty cages created more noise at higher frequencies compared with the loaded cages. The higher frequency noises are found to be the most disturbing to the human ear and hence the requirement to endeavour to attenuate these particular frequencies (Cox, 2008).

3.3. Discussion

Kerb-side deliveries were found to make a significant difference to the background early morning noise on the city streets. This was true whether deliveries took place in a ‘low noise sensitive area’ or on a busy street. The delivery operations generated peak sound levels which added from 14.7 dB(A) to 20.6 dB(A) to the background levels.

The events and equipment that caused the peak sounds were identified as (1) the running of the HGV tractor unit (2) the passage of the roll-cages along the floor of the HGV trailer and while transiting the tail-lift platform and the pavement in front of the shops (3) the manipulation and stacking of the returned empty cages. The focus of the research was on evaluating the noise caused by the manipulation of the roll-cages. As mentioned in the introductory chapter 1, the nuisance caused the HGV tractor unit engine and the refrigeration drive was effectively dealt with by asking the driver to switch off on arrival at the stores.

For an ambient HGV trailer delivering to store C, the manipulation of the roll-cages within the body produced an LA_{eq} of 72.7 dB(A) and an LAF_{max} of 79.1 dB(A) as described in Figure 3.3 and Table 3.2. The return of the empties to the truck and onto the tail-lift generated an LA_{eq} of 71.7 dB(A) and an LAF_{max} of 83.2 dB(A) as per Table 3.4. The additional examples for stores, A and B described in Appendix I.0 confirm these readings.

The spectras for the empty roll-cages were characterised by a concentration of “signature” frequencies around 1,000 Hz to 2,000 Hz while the full roll cages showed a spread across a broader range of frequencies.

The pure tones or tonal quality (as defined in the glossary of terms) that causes most annoyance were identified by an increase of 3 dB or more at the peak events. This occurrence can for example be seen from an examination of the spectra shown in Figure 3.6 which for the movement of empty roll-cages, where a pure tone at 1,000 Hz can be seen.

When comparing the measurements taken in Dublin with measurements recorded in the Netherlands, the measurements recorded by DIT should be adjusted by adding 6.6 dB(A) to the readings recorded by TNO for similar events in order to correct for the closer positioning of the sound meter in accord with BS 4142 compared with the TNO procedure. If the night time noise limits which apply to Dutch cities were to be applied to Dublin, the peak limit for delivery operations would be LA_{eq} 66.6 dB(A). The challenge for deliveries in Dublin is therefore to attenuate the peak sounds created by the roll-cages to within peak limits approaching LA_{eq} 66.6 dB(A).

In measuring statistical significance or error margins for noise measurements the convention is to allow for a margin of ± 1.5 dB(A) (Enfonics, 2008).

CHAPTER 4. DEVELOPMENT OF AN ACOUSTIC COATING

4.0. Introduction

As described in Chapter 3 field trials were carried out to measure the noise excesses or “exceedences” caused by night time deliveries and to identify the particular events that cause most disturbances. It was found that the passage of roll-cages across the floor of the HGV and the tail-lift platform emitted high sound pressure greater than 70 dB(A) at frequencies of 1,000 Hz and above and that this was one of the most disturbing activities occurring during night deliveries.

It was proposed that the most practical solution meriting development was to apply an acoustic coating which could dampen the sound and vibrations emanating from the floor of the HGV trailer and tail-gate during the manipulation of the roll cages.

Because the space inside the HGV trailer is at a premium and because the floor and kick-walls are subject to considerable wear, the development of a relatively thin and robust acoustic coating formulation was required. This was because the restricted dimensions of the HGV trailer could not accommodate the fitting of thick sound absorbing panels or of dense and heavy multi-layered noise transmission reducing panels or curtains to the walls or floor. The application of a damping coating to the affected surfaces was deemed to be an effective way of damping the high signature frequencies generated by the passage of roll cages and to offer a relatively cheap retro-fit solution.

A methodology was proposed and agreed to evaluate the new acoustic paint formulation under development by CREST in collaboration with General Paints Ltd. The requirements for the new acoustic coating were discussed with the fleet operator and with the vehicle body builder involved in the Innovation Partnership project, and these are outlined in Table 4.1:

Table 4.1. Requirements for an acoustic coating.

Parameters	Requirements
Identify the type of substrate materials to be coated	To coat a chequered “barley seed” aluminium HGV trailer floor and mild steel tail-lift platform (see figures 4.20 and 4.21)
Determine the dimensions of HGV trailer floor	13.2 meters long x 2.4 meters wide
Determine the areas of the HGV to be coated and which are subject to impacts.	HGV trailer floor, kick-walls and tail-lift platform
Determine the thickness of the coating acceptable to General Paints Ltd.	~ 0.5mm to 2mm
Assess ability to withstand temperature ranges for a multi-temperature HGV trailer unit	Range from – 22 °C for frozen goods, to + 25 °C for dry goods
Assess ability to withstand cleaning agents used by the fleet operator	Sodium hydroxide solution, pH 13
Assess service life of HGV trailer	6 years
Establish the frequency of servicing of HGV trailer	2 times per year

The focus of this chapter is on the development of the acoustic requirements of the coating; the durability and other requirements specified by the fleet operator were addressed by the relevant Innovation Partnership partners.

4.1. Methodology and experimental results

As described earlier in Chapter 2, the approach and methodology involved the following steps -

1. A literature review of the availability, characteristics and performance of commercially available acoustic coatings which could dampen the high signature frequencies created by the manipulation of roll-cages inside a HGV trailer.

2. The development of relatively simple test procedures for the acoustic pre-screening in the laboratory of formulations developed by CREST.
3. Acoustic trials of large coated panels on board an HGV trailer unit and tail-lift platform.
4. Durability tests in the laboratory and by using the carousel test rig located in the DIT HGV workshop.

4.2. Literature review

A review of the commercially available acoustic coatings was conducted as part of the Innovation Partnership project. Information searches on acoustic materials and damping compositions were conducted on the World Surface Coatings Abstracts and on the European Patent Office websites. Information was also obtained from coatings journals and from various suppliers' data sheets. The keywords that were used for these searches were "acoustic", "compositions", "noise reduction", "damping", "vibration", "flooring", "viscoelastic", "paint" and "panels" (CREST / DIT, 2007).

The patent search focused on compositions containing viscoelastomeric polymers that were formulated with or without polyurethanes and on epoxides or acrylics. These compositions are known to impart a damping function across wide temperature ranges. Conventional acoustic floor compositions were found to be elastomeric type coatings that use various additives and that are applied as solvent based spray-coatings.

Helpful advice was obtained through the Dutch science and technology agency, Senter Novem on trials completed on a wide selection of acoustic coatings. These trials were conducted on behalf of the Association of Dutch Vehicle Body Builders (FOCWA, 2006).

The Dutch association of vehicle body builders specified the following requirements in their evaluation of 22 different formulations; sound damping at acceptable thicknesses: rapid and easy application: excellent bonding to the substrates used on HGV trailers, namely aluminium and mild steel: good abrasion and impact resistance:

good chemical resistance: heat and cold resistance. These requirements were thought likely to be similar to the requirements of the Irish fleet operators.

The test results reported by the Senter Novem, who were external partners in the Irish Innovation Partnership project, set the benchmark by which a new and competing formulation was developed. The Irish paint supplier, General Paints Ltd., felt that the focus should be on developing an innovative water based acoustic coating with a final hard polyester top layer, unlike the Dutch who focussed on polyurethane solvent-based paints which require high temperature pre-heating before application. Water based paints have the advantages that they can be applied without special expensive binary heated portable spray-heads and are more environmentally friendly.

Following the literature survey and on the recommendation of Senter Novem, a number of commercially available coatings were sourced with which to make comparisons. The best performing of these was “TechCoat” supplied by the Polymer Chemical Company B.V., Postbus 287, NL-5280 AG Boxtel NL: (Elastogran, 2006). Senter Novem advised that the Dutch experience suggested that any coating that could achieve a reduction approaching 5dB would be very acceptable to the vehicle body builders (Senter Novem, 2006).

The literature search revealed the commercial availability and technical characteristics of a wide range of damping adhesives used in the automotive industry to which any new acoustic coating could be compared (Rousch Industries 2006; Acoustics 2006; Sound Service 2006; Acousti Products 2006; ABD Technology 2006; Super Soundproofing 2006). Of particular relevance was a review of damping materials by Lewis H. Bell and Douglas H. Bell in the textbook entitled “Industrial Noise Control” (Bell and Bell 1994, Chapter 6.3) and by P. Weddell of the University of Bradford School of Engineering Design and Technology, (2005).

From this information a materials matrix was structured and a series of first generation paint formulations were developed for screening. Five water-based proprietary formulations were developed and applied initially in the laboratory to small aluminium and mild steel panels.

4.3. Laboratory tests

Durability and abrasion tests were first of all performed on the newly formulated paints according to the relevant ASTM and BS standards. Tests included an estimation of the % solids used, drying time (ASTM D 5895-96), pencil hardness (ASTM D 3363), scratch hardness impact resistance (ASTM D-2794), dry film thickness, adhesion (BS EN ISO 2409:1995) and Taber abrasion (ASTM D-4060-95) measurements. The results were tabulated and ranked (CREST-DIT, 2007). In parallel with these durability tests, complementary acoustic impact trials were designed and these particular experiments are described.

4.3.1. Falling weight vertical tube test

Acoustic pre-screening was performed by using a modified version of the standard measurement procedure for the impact resistance of paints using the deformation technique. This test was an adaptation of standard ASTM 2794, Designation D 2794-93 procedure which is used to measure deformation (ASTM 2794). The noise was measured in accordance with the industrial noise measurement standard BS 4142 (British Standard, 1997).

The test involved measuring the maximum sound pressures emitted upon the impact of a 0.907 kg (2 lb) machined weight dropped from a height of 635 mm (25 inches) onto small aluminium coated panels measuring 150 x 100 mm and 100 x 100 mm, respectively. Each candidate coated sample was placed at the base of the apparatus. The apparatus comprised a vertical tube designed to guide a cylindrical weight which was dropped repeatedly on to a punch resting on the small plate under test.

The noise levels were read upon the impact of each drop using a Bruel and Kjaer Type 2260 sound meter. The B&K sound meter was placed at a distance of 3.5 meters from the source and at a height of 1.2 meters by placing it on a tripod. Having recorded the background noise in the laboratory for a period of 4 minutes, the falling weight cycle was repeated 10 times for both the coated and uncoated sides of the test panels and the sound pressure levels were recorded. LAF_{max} (maximum sound pressure recorded for a period of 0.125 seconds) was the parameter used to measure the peak sound level

recorded on the impacting of the falling weight. An interval of several seconds was observed between collisions before a peak reading was taken in order to allow the vibrations to subside. The logarithmic averages of the 10 impact sounds were calculated for each coated sample under test. The LAF_{max} parameter was considered to be a convenient way of comparing the peak sound attenuation characteristics of the different coatings (Enfonic, 2007).

Two batches of samples were acoustically tested. The first batch “A” comprised five different coatings on the smaller aluminium plates. The second batch “B” comprised different coatings on the larger panels. The peak noise reductions achieved for batches A and B were calculated by comparison with those recorded for the aluminium uncoated plates of similar dimensions.

Four different formulations prepared by CREST and labelled 1 to 4, were applied to both the smaller A batch panels and to the larger B batch panels. Formulations 1 to 4 were confidential to CREST / DIT and to General Paints Ltd. A fifth Dutch sourced proprietary coating labelled V was also tested in order to make comparisons (Elastogran, 2007). The coatings were brushed on and allowed to air dry for 24 hours prior to successive coatings and the thicknesses recorded varied between 321 μm and 1500 μm and averaged 700 μm , because of the imprecise brush applications.

The falling weight vertical tube apparatus is illustrated in Figure 4.1.

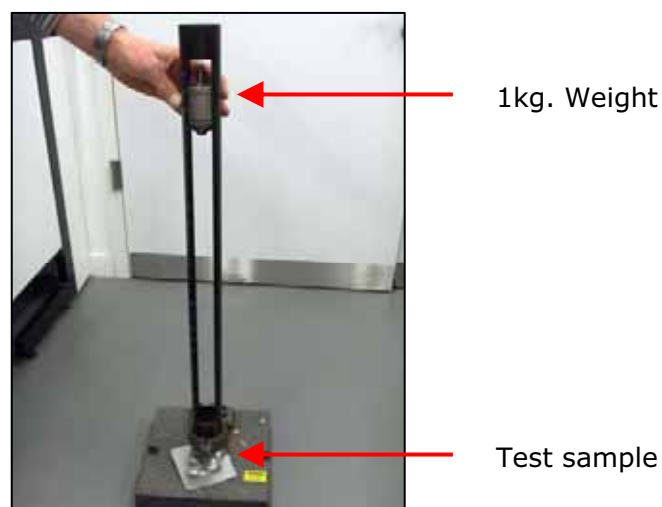


Figure 4.1. Photograph of smaller falling weight tube test

The results of the falling weight tube test are summarised in Tables 4.2 and 4.3 below and are described in more detail in Appendix II.0. This shows that formulation 1 as applied to batch A (the smaller 100 x 100 mm panels) and also to batch B (the larger 150 x 100 mm panels) gave the best results. In the case of the batch A panels, formulation number 1 showed a reduction of 5.5 dB(A) while the Dutch proprietary coating (number 5) showed a smaller reduction of 2.3 dB(A). In the case of the batch B panels a reduction of 4.7 dB(A) was recorded for formulation 1 which again compared favourably with the Dutch proprietary coating (formulation 5) which showed a much smaller reduction of 1.8 dB(A).

Table 4.2. Results of falling weight tube tests – Comparisons of noise reductions achieved from the batch A tests of different coated aluminium panels.

Batch A panels (10x10cm) coated with formulations 1 to 4 and compared with proprietary coating 5	Logarithmic average dB(A) reductions compared with an uncoated panel.
1A	5.5
2A	3.1
3A	4.5
4A	2.2
5A	2.3

Table 4.3. Results of falling weight tube tests – Comparisons of noise reductions achieved from the batch B tests of different coated aluminium panels

Batch B panels (15x10cm) coated with formulations 1 to 4 and compared with proprietary coating 5	Logarithmic average dB(A) reductions compared with uncoated panel.
1B	4.7
2B	1.8
3B	1.9
4B	3.2
5B	1.8

On the basis of these preliminary trials, “Formulation 1” was selected for further development and evaluation because it gave the best acoustic performance.

4.3.2. The larger scale falling weight and pendulum test rigs

Following completion of the first series of tests the most promising Formulation 1 was acoustically assessed on two specially constructed rigs. The coating was applied to 1

m² panels comprising aluminium and mild steel substrates and these panels were subject to (a) a larger scale falling weight test and to (b) a pendulum impact test.

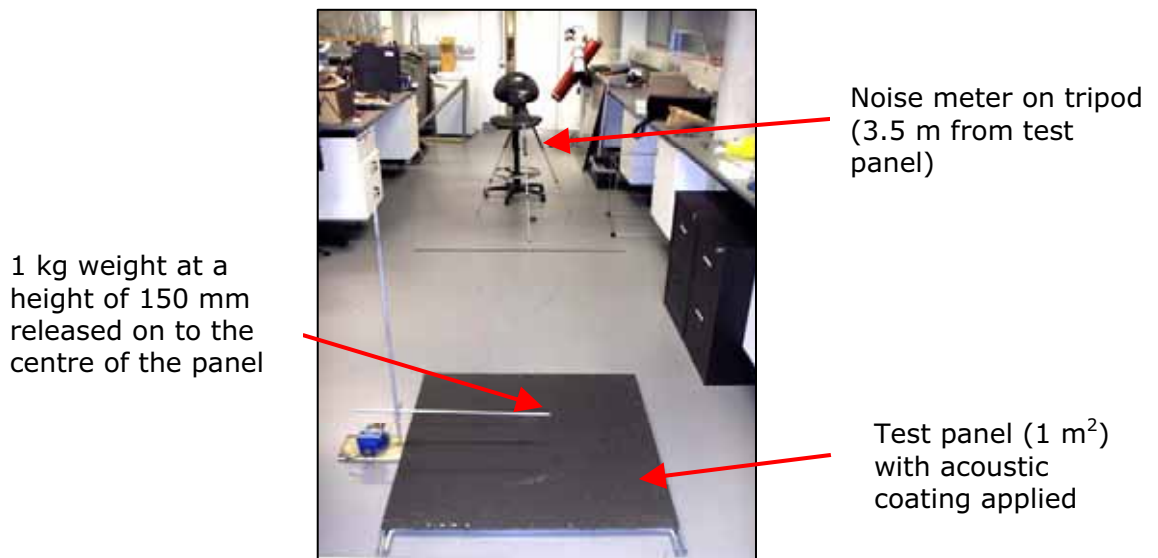


Figure 4.2. Photograph showing the set up of the larger falling weight test rig

The purpose built test rigs were fabricated in the engineering workshops and were designed to be portable so that they might be used both in the laboratory and subsequently on board an HGV trailer unit. The Falling Weight and Pendulum Test rigs are illustrated below in Figures 4.2 and 4.3.

4.3.2.1. The falling weight test (larger scale)

As mentioned earlier the falling weight apparatus was designed to simulate the noise caused by objects impacting upon the floor of a trailer unit or with the tail-lift platform and to further evaluate the effectiveness of the new coating. Panels of 1 m² of uncoated and coated substrates were tested. These substrates comprised (1) chequered aluminium (2) mild steel (3) GRP.

The test rigs were also used to compare the performance of the new acoustic formulation with proprietary adhesive damping strips, namely “Ygro Σ -Dead Eliminator” (item number EDE01) and “ Σ -Dead Original” (item number EDT01). These products were supplied by Ygro UK Ltd. in the UK (2006). The “Ygro” adhesive damping strips were selected and sourced following a review of the

commercially available damping materials carried out as a part of the Innovation Partnership project by CNMR (2006).

The following test procedures were followed. The candidate panels were clamped to a 1 m² steel frame so that they could vibrate freely when struck by the falling weight. The 0.907 kg (2 lb) weight was then repeatedly dropped from a measured distance of 150 mm onto the centre of the panel. The procedure was repeated 10 times on both the coated and uncoated sides of the panels, allowing for a pause of 3 or more seconds between measurements. The microphone was placed at a distance of 3.5 meters from the centre of the panel under test and LAF_{max} noise measurements were recorded on the B&K sound meter. The LAF_{max} measurements were recorded, logarithmically averaged and compared for the three different substrates under test; aluminium, mild steel and GRP (Glass Reinforced Plastic).

Frequency spectra were developed in order to see how the noise attenuation varied across the frequency ranges for the different uncoated and coated substrates.

The performance of the new acoustic coating was also compared with panels partially covered with the two proprietary damping “Ygro” adhesive strips. These strips were cut to cover 1/3 of the surface areas on the rear smooth sides of the chequered aluminium and steel panels. According to Bell et al and to the supplier “Ygro”, it was deemed sufficient to cover 1/3 of the panel surface area with the damping strips in order to achieve optimum damping effects (Bell and Bell 1994; Ygro 2006).

The tests were carried out on the coated chequered sides of the mild steel and aluminium panels and on the smooth GRP panel and the noise reductions were calculated with respect to the peak impact sounds on similar uncoated panels. The results are summarised in Table 4.4.

Table 4.4. Summary of noise reductions achieved by the application of an acoustic coating and damping strips to GRP, mild steel and aluminium panels using the falling weight test

Substrate	Uncoated Log. Average dBA (LAF_{max})	Coated Log. Average dBA (LAF_{max})	Reductions in dB, coated panels compared with uncoated
Aluminium, chequered side	102.9	88.1	14.8
Aluminium, plain side, plus “Ygro”	104.3	88.8	15.5
Mild Steel, chequered side only	100.3	85.6	14.7
Mild steel, plain side, plus “Ygro”	99.6	90.3	9.3
GRP	98.3	91.2	7.1

It can be seen from Table 4.4 above that the coating attenuated the peak sound on the aluminium panel by 14.8 dB(A) and the peak sound on the mild steel by 14.7 dB(A). In contrast the proprietary “Ygro” damping strips showed lower corresponding reductions of 14.1 dB(A) and 10.0 dB(A) respectively. This indicated that the proprietary damping adhesive strips were less effective than the new acoustic coating.

4.3.2.2. Pendulum tests

This test was devised to simulate the sound radiated by the walls and floor of the trailer body when struck by roll cages and by clamping bars. The test rig comprised a pendulum mounted on a portable steel structure. The rig was designed to secure 1 m² panels in an upright position. The test panels were sandwiched between the vertical upright frame and the demountable frame by four clamps and spacers by means of a torque of 10 Nm. The correlation between the clamping loads and the natural frequency and excitation of the panels was also further investigated as described in 4.5.2. The test rig is illustrated in Figure 4. 3.

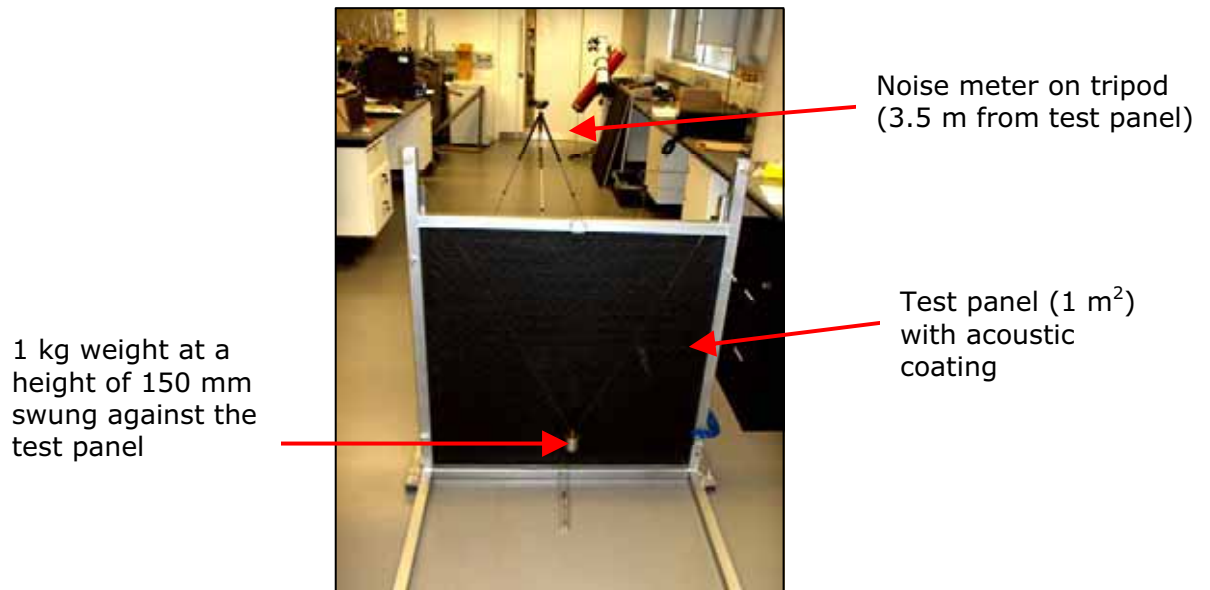


Figure 4.3. Photograph showing the set up and steel framework for the pendulum test rig

The tests involved clamping the candidate panel to the uprights of the structure by means of the de-mountable frame. The steel weight was suspended from a wire secured to two points on either side of the top of the frame and the suspended weight was designed to strike the panel at a distance of 150 mm above the base of the frame.

Before starting the pendulum tests the background noise level in the laboratory was recorded for 2 to 3 minutes. The weight was then released at a distance of 150 mm from the front of the panel and caught after each collision and the noise level of each impact was recorded at a distance of 3.5 m. by the B&K sound meter mounted 1.2 meters above the floor on a tripod.

The procedure was repeated 10 times, allowing for a pause of several seconds between impacts. LAF_{max} levels were recorded for each impact. Samples of uncoated and coated GRP substrates were tested and the results compared and similar comparisons were made in the case of the coated and uncoated aluminium and mild steel panels.

As was the case with the falling weight test, the following samples were evaluated, (1) smooth GRP panels, uncoated and coated (2) aluminium chequer plated panels, uncoated and coated (3) mild steel chequer plated panels, uncoated and coated. The results of the tests are summarised in Table 4.5 below.

Table 4.5. Summary of noise reductions achieved by the application of an acoustic coating to GRP, aluminium and mild steel panels using the pendulum test.

Substrate	Uncoated Log. Average dB LAF_{max}	Coated Log. Average dB LAF_{max}	Reductions in dB - coated panels compared with uncoated
Aluminium chequered side	92.0	70.2	21.8
Mild steel, chequered side	87.4	72.9	14.5
GRP	86.8	74.7	12.2

From Table 4.4 it can be seen that the application of the acoustic coating to the smooth GRP showed a reduction of 12.2 dB(A). The application of the coating to the chequered face of the aluminium panel gave a reduction of 21.8 dB(A) while the application of the coating to the chequered mild steel gave a reduction of 14.5 dB(A).

By contrast the stated values for the corresponding results for the falling weight tests reported in Table 4.4, showed reduction of 14.8 dB for the coated aluminium and 14.7 dB for the coated mild steel. These reductions are similar for both the pendulum and falling weight tests.

It was decided to see if similar promising results could be repeated in the field on board a full scale HGV trailer unit. Before going out into the field for further assessment however, it was deemed appropriate to look more closely at the damping characteristics of the coated panels by measuring the ⁴decay times of the vibrations on an oscilloscope.

⁴A measure of the decay of acoustical signals, expressed as a slope in dB/second. The rate at which a signal drops off. (BKSV, 2008)

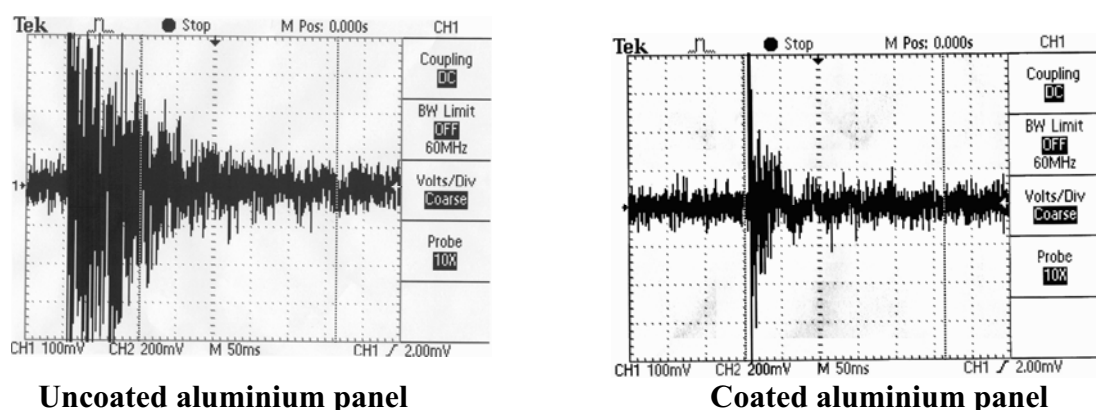
4.4. Effect of the acoustic coating on the reverberations and decay time measurements

⁵Reverberation experiments were carried out on the 1 m² aluminium and mild steel panels tested earlier. The experiments were carried out as a part of a final year BSc. Project (Ryan, 2007).

An uncoated aluminium panel was impacted by the pendulum weight and the sound of the collision was then displayed on an oscilloscope. The oscilloscope was set to trigger when the pendulum collided with the panel. The intensity was displayed on an oscilloscope which also showed how it varied with time. This exercise was repeated using a coated panel and the results compared. The displays appearing on the oscilloscope are shown in Figures 4.4 and 4.5. It can be clearly seen that the coating had a significant damping effect in terms of reducing the intensity of the sound and its decay time.

4.4.1. Reverberation effect on coated and uncoated aluminium and mild steel panels compared

The decline in the decay rate on striking the aluminium panel can be seen by comparing the two graphs shown in Figure 4.4.



Uncoated aluminium panel
Coated aluminium panel
Figure 4.4. Graphs comparing the decay times for the impacts of the pendulum on coated and uncoated aluminium panels (Ryan, 2007).

⁵ The persistence of sound in an enclosure after a sound source has been stopped. It is a measure of the persistence of an impulsive sound in a space as well as of the amount of acoustical absorption present inside a space. The tailing off of sound in an enclosure because of multiple reflections from the boundaries. (BKSV, 2008)

The impact tests were also repeated on coated and uncoated mild steel panels at 1,000Hz. The reductions in the intensity and decay times can be seen by comparing the two graphs in Figure 4.5.

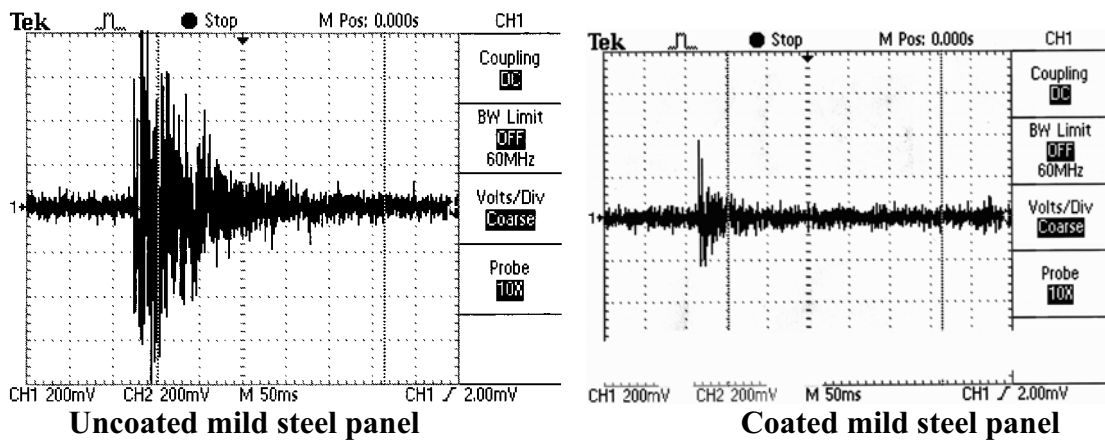


Figure 4.5. Graphs comparing the decay times for the impacts of the pendulum on coated and uncoated mild steel panels (Ryan, 2007).

It can be seen that the coating made a significant difference to the decay time. The decay time was reduced from an average of 200 milliseconds to 50 milliseconds for the coated aluminium panels, while a reduction of 100 milliseconds to 25 milliseconds was recorded for the coated mild steel coated panel. These damping effects and measurements are discussed with reference to the theories described in Chapter 2 (Methodology & Theory) and with reference to the final year project report (Ryan, 2007). The likely effects on damping of the substrate thicknesses and densities were considered.

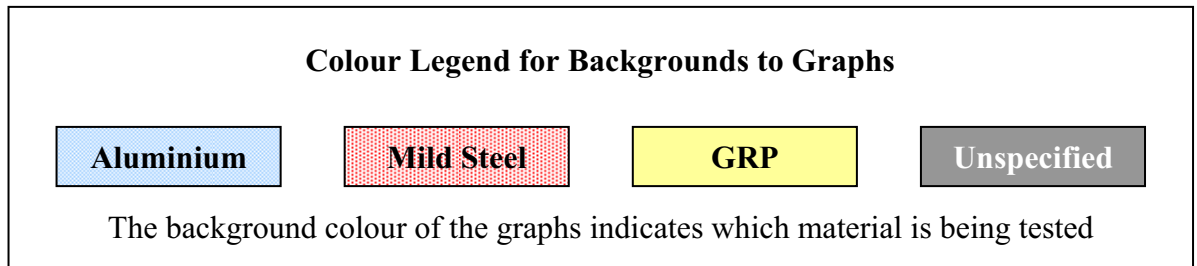
4.5. Analysis and interpretation of the acoustic experiments in the laboratory across the frequency range

Having measured the noise reduction achieved by the application of the acoustic coating and other damping materials to the substrate panels it was decided to investigate how the different frequencies were affected. This was done by downloading spectra for selected impacts caused by the falling weight and by the pendulum. The spectra were developed for selected typical noise events generated by the impacts.

The first series of experiments involved comparing the acoustic properties across the frequency range for aluminium, mild steel and GRP. The second series assesses how the substrates behave when the acoustic coating and proprietary damping materials are applied. The following results are presented in the sequence of aluminium, mild steel and GRP and the graphs are colour coded accordingly.

4.5.1. Comparing the properties of the different substrates across the frequency range.

The colour legend used to distinguish between the different substrates is shown in the legend.



A series of spectra were developed and compared in order to see at what particular frequencies the coating had most effect and to distinguish between the performances of the coating on the three different substrates.

4.5.1.1. Impact spectra for aluminium and mild steel using the falling weight test.

Spectra are illustrated below which compare the performance of the aluminium, mild steel and GRP substrates when subjected respectively to the falling weight and pendulum tests. In the first instance the spectra for the uncoated aluminium and mild steel substrates were developed when subjected to the falling weight test as shown in Figure 4.6. These spectra can be represented either as bar charts or as line graphs. According to Bruel and Kjaer, the former is favoured for plotting impact sounds against frequencies and the latter for plotting the frequencies against time, but both presentations are illustrated respectively in Figures 4.6a and 4.6b. Bruel and Kjaer advise that the bar graph presentation ‘is more typical for Octave or $\frac{1}{3}$ Octave frequency analysis’ (Duffy G, Enfonc Ltd, 2008). For this reason all spectra subsequent to Figures 4.6 are represented as bar charts only, they are linear and are not A-weighted to simulate the human ear.

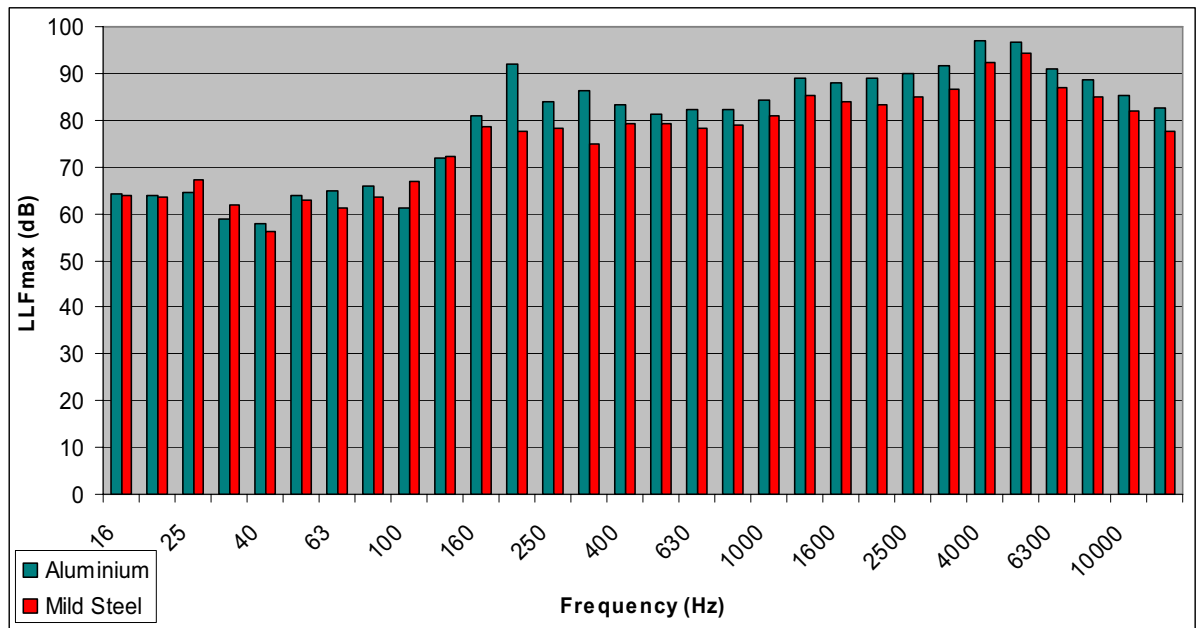


Figure 4.6(a). Spectra of a falling weight test comparing an uncoated aluminium substrate with an uncoated mild steel substrate shown as a bar chart.

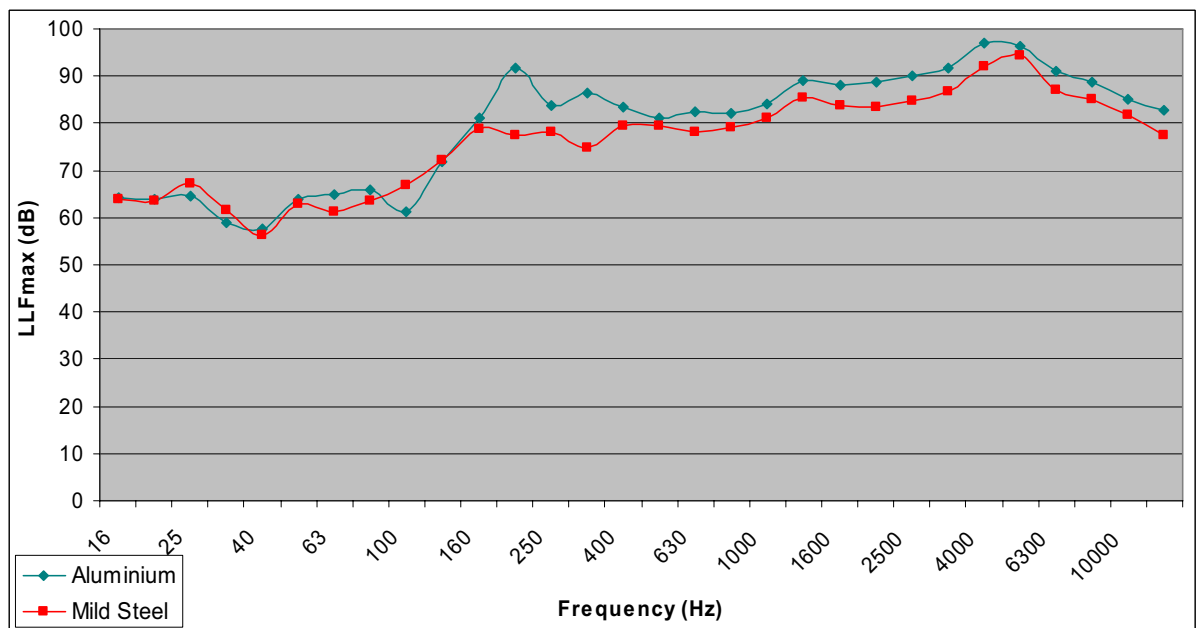


Figure 4.6(b). Spectra of a falling weight test comparing an uncoated aluminium substrate with an uncoated mild steel substrate shown as a line graph.

Secondly a spectra comparing the impacts on coated aluminium with mild steel panels was prepared, as illustrated in Figure 4.7 below.

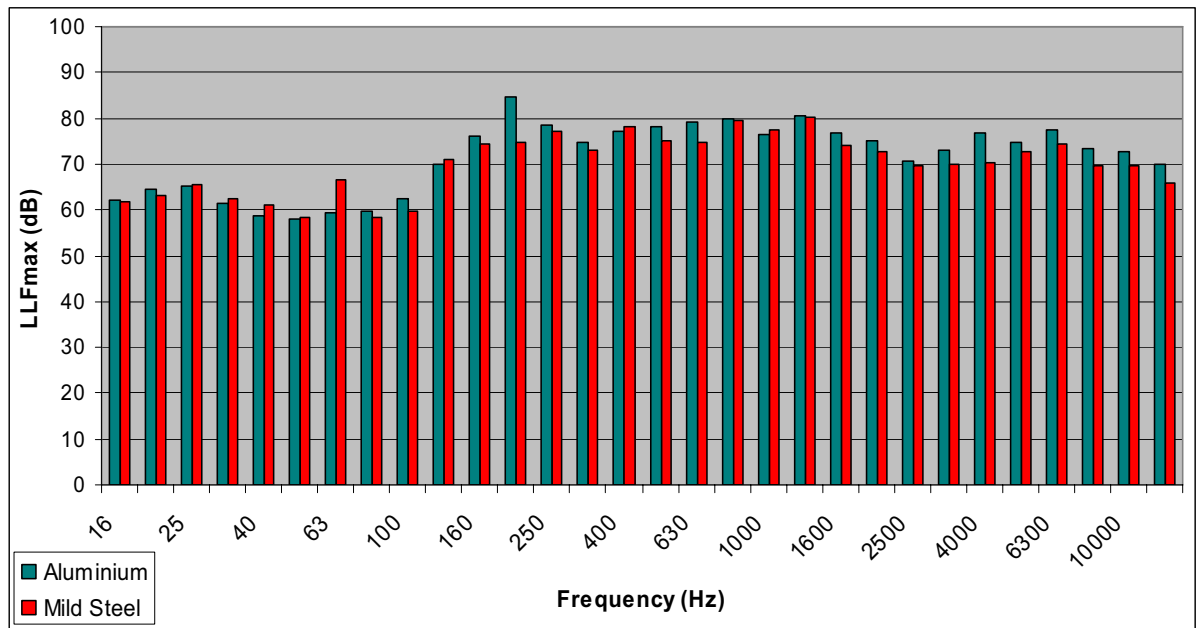


Figure 4.7. Spectra of a falling weight test comparing a coated aluminium substrate with a coated mild steel substrate.

It can be seen from Figures 4.6 and 4.7 that both the aluminium and mild steel substrates follow a broadly similar pattern across the frequency range for both the coated and uncoated panels. The aluminium panel however, gave higher sound readings across the frequency spectrum with a peak sound being discerned at 250 Hz in the case of both the uncoated and coated substrates.

This higher peak sound for aluminium may be due to the fact the aluminium panel was of smaller cross section and was less dense than the mild steel panel. The lighter aluminium panel had a 5 fingered pattern (also known as tread / chequer plate aluminium with a raised pattern of repetitive 5 diamond shaped ridges) whereas the mild steel had a single diamond pattern (similar to a 5 finger pattern where there is a repetitive pattern of a single ridge at right angles to one another) and this more complex pattern together with its thinner cross section, will also have affected the rigidity of the aluminium allowing it to vibrate more easily. The diamond plated mild steel panel had a thickness of 2.9 mm while the barley seed aluminium panel had thickness of 2.6 mm (measured from the base to the top of the teeth).

The relative densities of the two substrates were compared. They were quoted as 7.8 kg/m³ (Hypertextbook.com, 2007) for mild steel and 2.7 kg/m³ (Zyra.org, 2007) for

aluminium. It is therefore assumed that the denser steel substrate was able to absorb and dampen the impacts more effectively than the lighter aluminium.

The frequency spectra for the uncoated and coated aluminium and mild steel substrates when subjected to the pendulum test are compared in Figures 4.8 and 4.9. As was the case with the falling weight test shown in Figures 4.6 and 4.7, the uncoated aluminium and mild steel followed a similar pattern across the frequency spectrum, except that the 250 Hz peak was not in evidence with the pendulum test. Another contrast was that the coated aluminium showed more attenuation compared with the coated mild steel at frequencies above 1,000 Hz, the reverse of what was recorded with the falling weight test. For both substrates, the coating was effective in damping the peak sounds at frequencies above 1,000 Hz.

By comparing Figure 4.8 with 4.9 it can be seen that the uncoated and coated GRP panels showed roughly similar results having peaks at 63 Hz, and did not follow the patterns recorded for the aluminium and mild steel. This was expected to be having regard to the greater densities of the metal substrates.

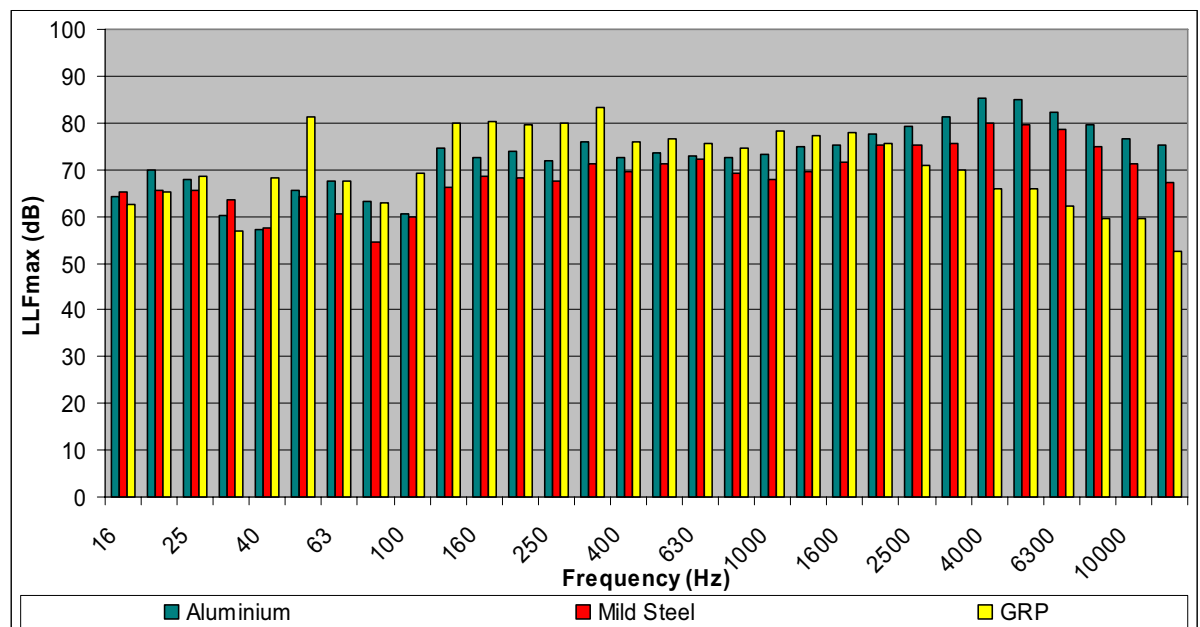


Figure 4.8. Spectra comparing uncoated aluminium, mild steel and GRP substrates using the pendulum test.

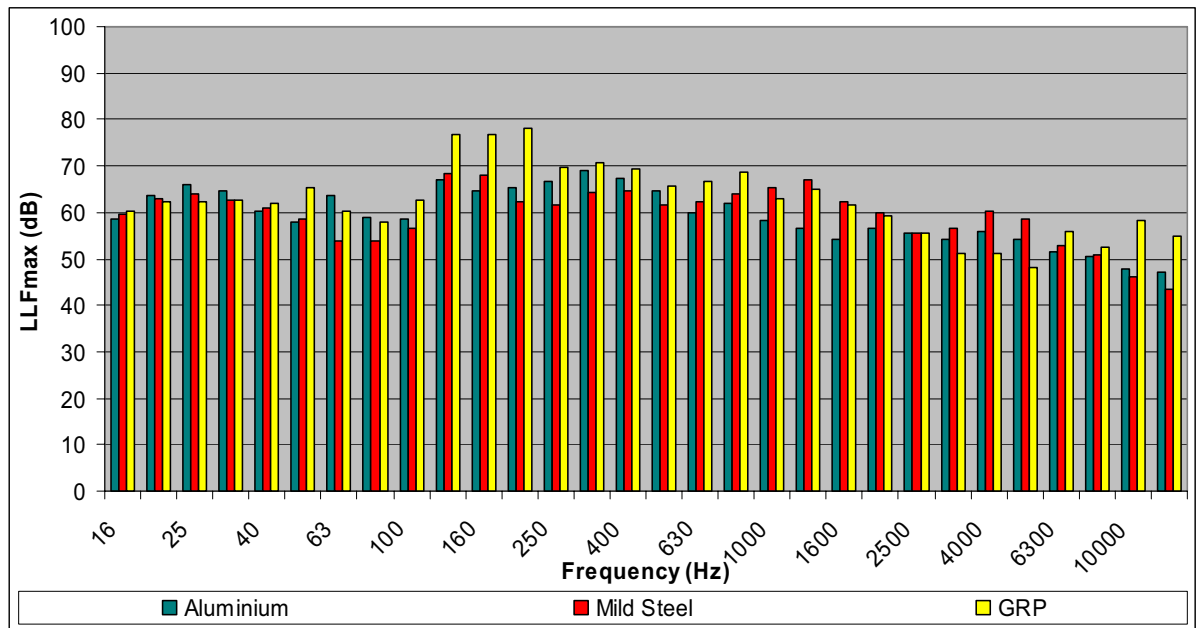


Figure 4.9. Spectra comparing the coated aluminium, mild steel and GRP substrates using the pendulum test.

From Figure 4.8 it can be seen that the behaviour of the uncoated aluminium and mild steel was roughly similar across the frequency range when subjected to the pendulum tests as was also the case with the falling weight tests shown earlier in Figure 4.6. The behaviour of the GRP was very different to the two metal substrates as might be expected due to its different mechanical properties.

From Figure 4.9 it can be seen that the coated aluminium showed greater attenuation than the mild steel when subjected to the pendulum test, in contrast to what was reported for the falling weight test (Figure 4.7). Again as was expected the behaviour of the coated GRP was different to the other substrates.

4.5.1.2. Comparing the effects of the coating as applied to the different substrates.

The performance of the coating was examined further by superimposing spectra for coated and uncoated substrates developed from the falling weight and pendulum tests, as shown in Figures 4.10 and 4.11 for the aluminium, and in Figures 4.12 and 4.13 for the mild steel.

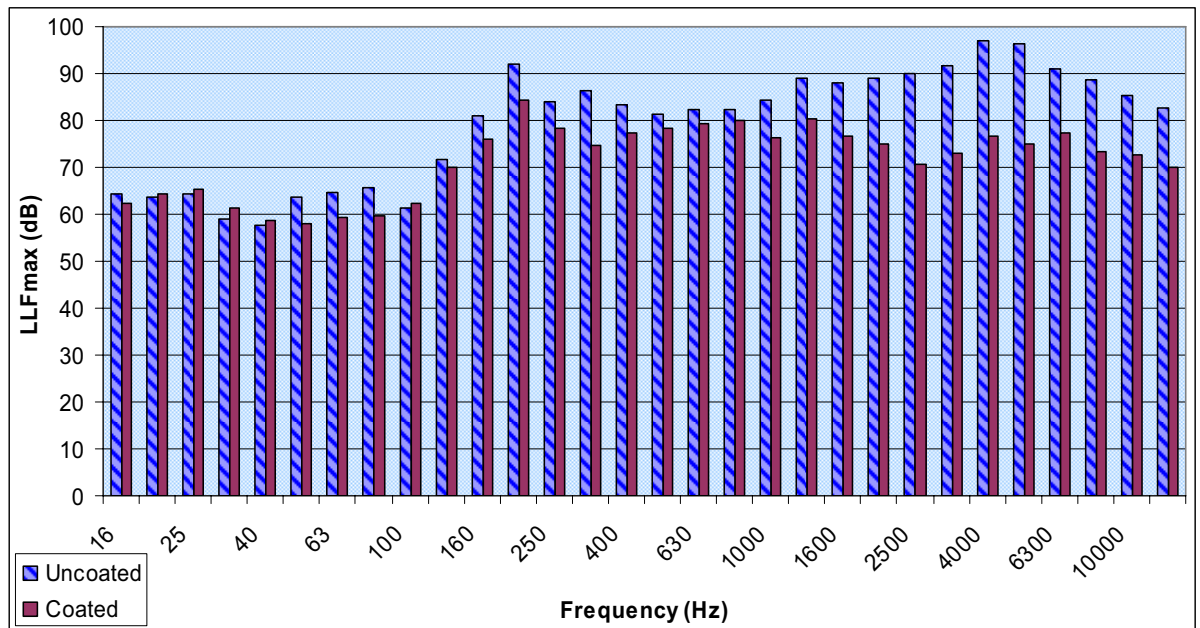


Figure 4.10. Spectra of falling weight tests comparing an uncoated aluminium substrate with a coated aluminium substrate.

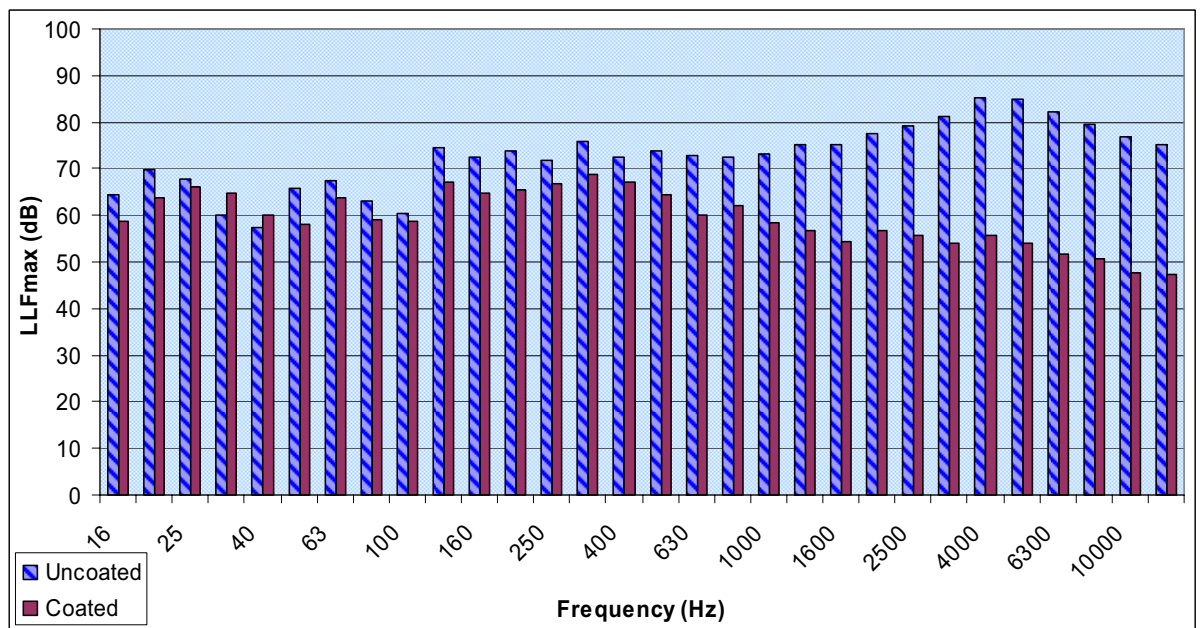


Figure 4.11. Spectra of pendulum tests comparing an uncoated aluminium substrate with a coated aluminium substrate.

The falling weight test spectra for the aluminium illustrated in 4.10 showed that the greatest attenuation was achieved at frequencies of 2,500 Hz and above; this was even more pronounced for the pendulum test illustrated in Figure 4.11, with significant attenuation beginning at the lower frequencies of 160 Hz.

In the case of the mild steel, spectra for the falling weight tests were superimposed and comparisons made between the coated and uncoated panels as shown in Figure 4.12. This exercise was repeated for the pendulum test as shown in Figure 4.13.

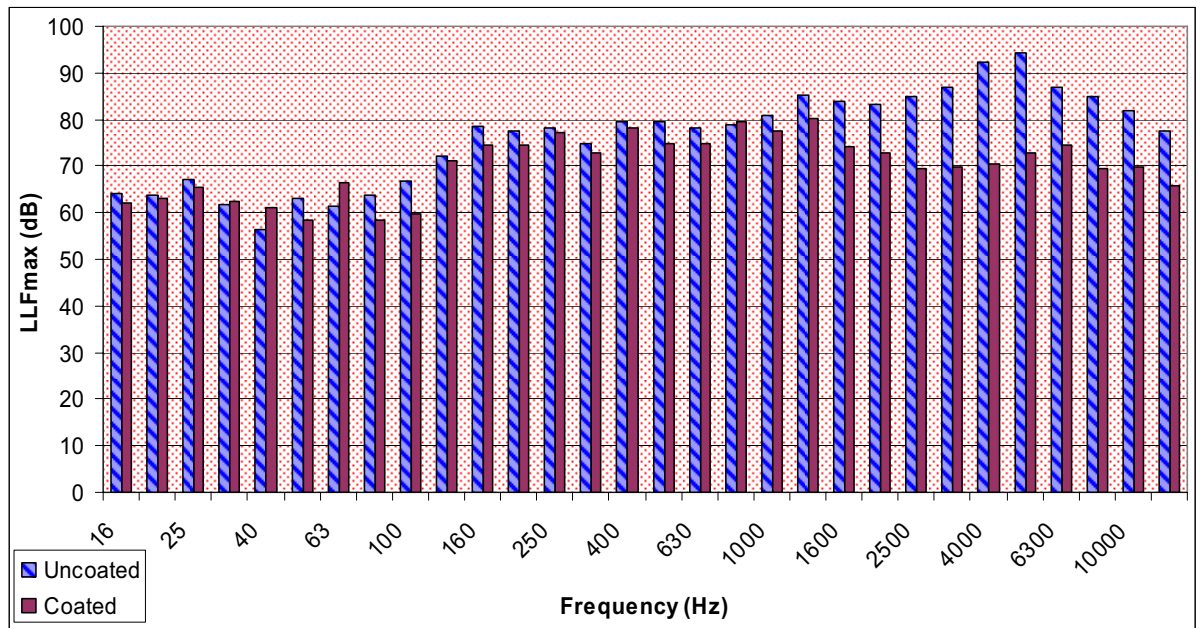


Figure 4.12. Spectra of falling weight tests comparing an uncoated mild steel substrate with a coated mild steel substrate.

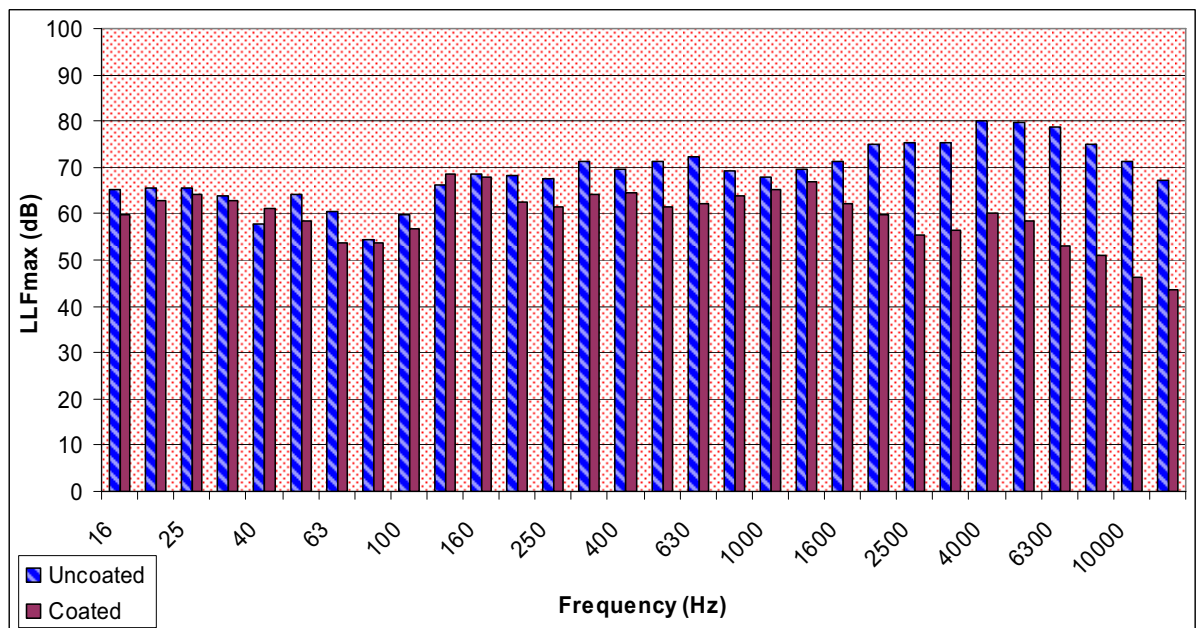


Figure 4.13. Spectra of pendulum tests comparing an uncoated mild steel substrate with a coated mild steel substrate.

For both sets of tests the greatest attenuations were achieved at 1,600 Hz and above. The pendulum tests showed better attenuation than did the falling weight tests at the higher frequencies.

The performance of the acoustic coating when applied to GRP was also examined by superimposing the pendulum test spectra for an uncoated and coated panel, as shown in Figure 4.14.

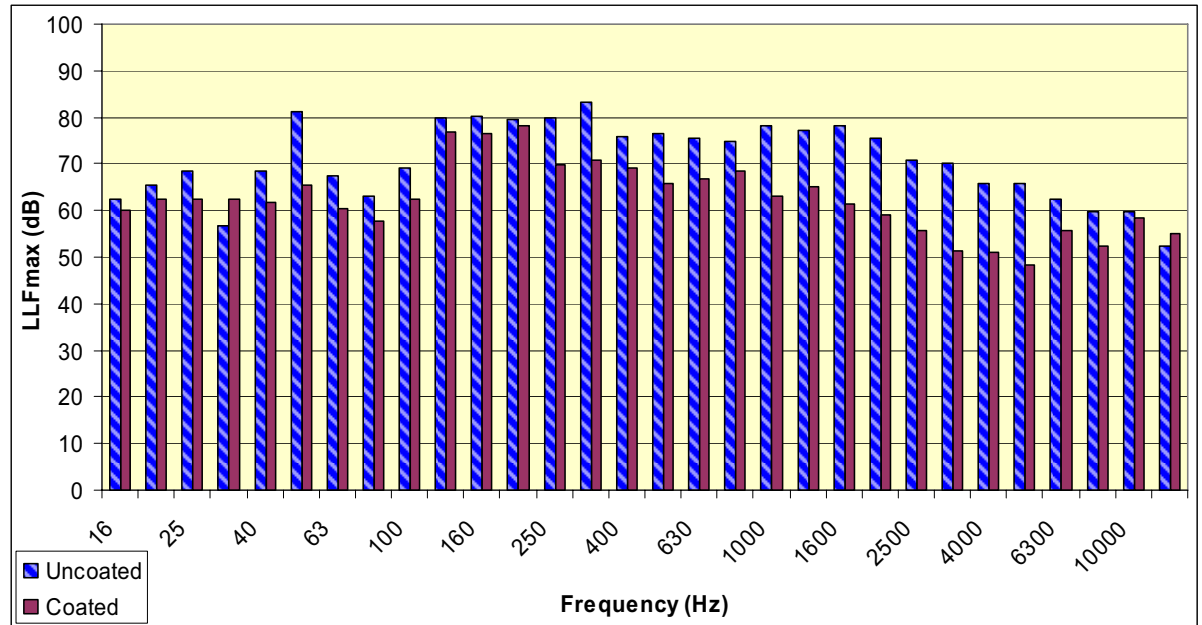


Figure 4.14. Spectra comparing an uncoated and coated GRP using the pendulum test.

It can be seen from Figure 4.14 that the coating gave greatest attenuation between 1000 Hz and 6000 Hz but that this pattern was not observed at the very high frequencies.

4.5.1.3. Comparison between falling weight and pendulum test results.

It was decided to superimpose the spectra from the falling weight tests on to the pendulum tests in order to see how the two different test results compared. This was done firstly in the case of the uncoated aluminium panel and secondly in the case of the coated aluminium. These comparisons are shown respectively in Figures 4.15 and 4.16.

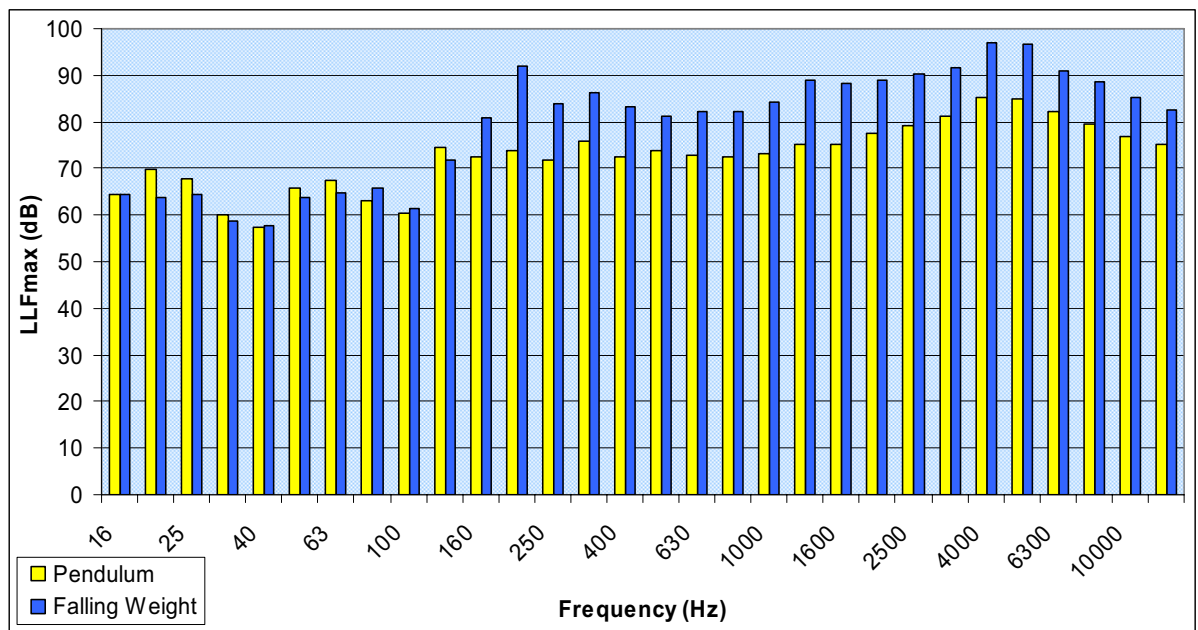


Figure 4.15. Comparison between the spectra for the pendulum test and the falling weight test for the uncoated aluminium.

It can be seen in Figure 4.15 that whilst up to 160 Hz the results were similar; above 160 Hz the falling weight test generated more noise. This may be explained because the two tests suffered different impact forces, a vertical force in the case of the falling weight test and a weaker horizontal force in the case of the pendulum. The falling weight test created more noise at the higher frequencies, because it was deemed to embody more kinetic energy and because the panel was not as securely clamped as it was for the pendulum test, allowing more unrestricted vibration. The characteristic aluminium peak of 250 Hz was again visible as was seen earlier in Figures 4.6 and 4.7.

Figures 4.15 and 4.16 show that the falling weight test was significantly louder by 10 dB compared with the pendulum test, particularly at frequencies of 250 Hz and above and that this was the case for both the uncoated and coated aluminium panels.

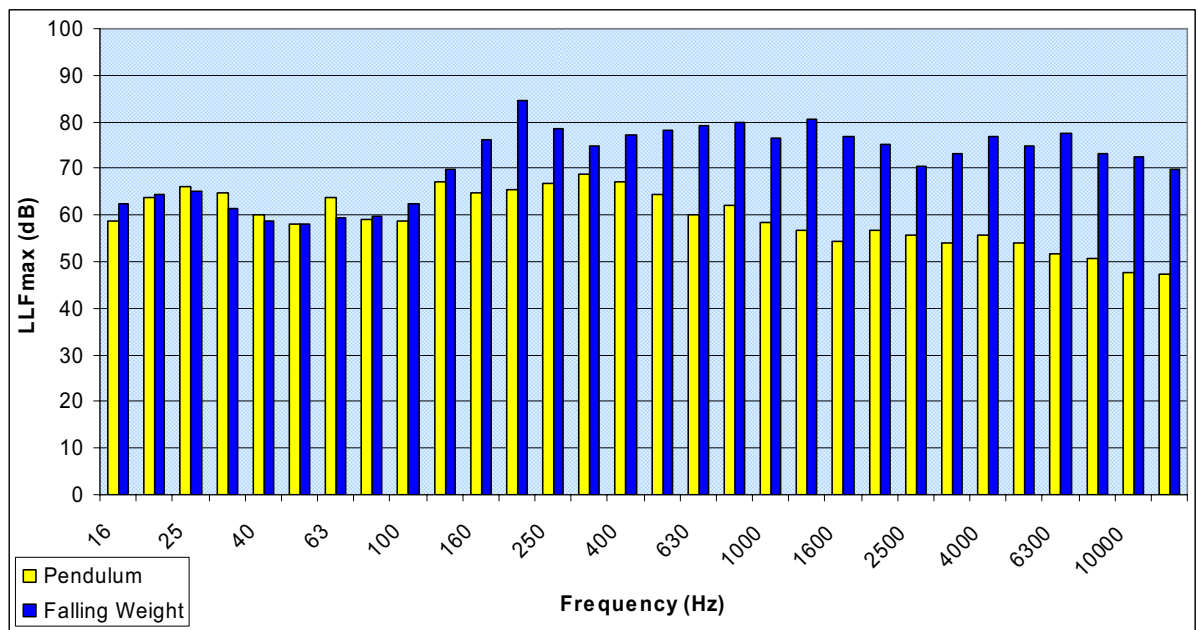


Figure 4.16. Comparison between the spectra for the pendulum test and the falling weight test for the coated aluminium substrate.

4.5.1.4. Comparison of the coating with commercially available damping materials applied to aluminium and mild steel

Proprietary damping adhesive strips, “ Σ -dead Eliminator” and Σ -dead Original” manufactured in the UK, were attached to the reverse sides of the aluminium and mild steel panels to cover 1/3 of the surface area, in order to compare their performance with the new acoustic coating under development. The falling weight test was applied and the spectra generated were superimposed as shown below in Figures 4.17 and 4.18.

From Figures 4.17 and 4.18 it is apparent the acoustic coating gave a better performance than either the Σ -dead Eliminator or Σ -dead Original. In the case of the mild steel, the coating was seen to be most effective at the higher frequencies above 1,600 Hz compared with the proprietary damping adhesive strips.

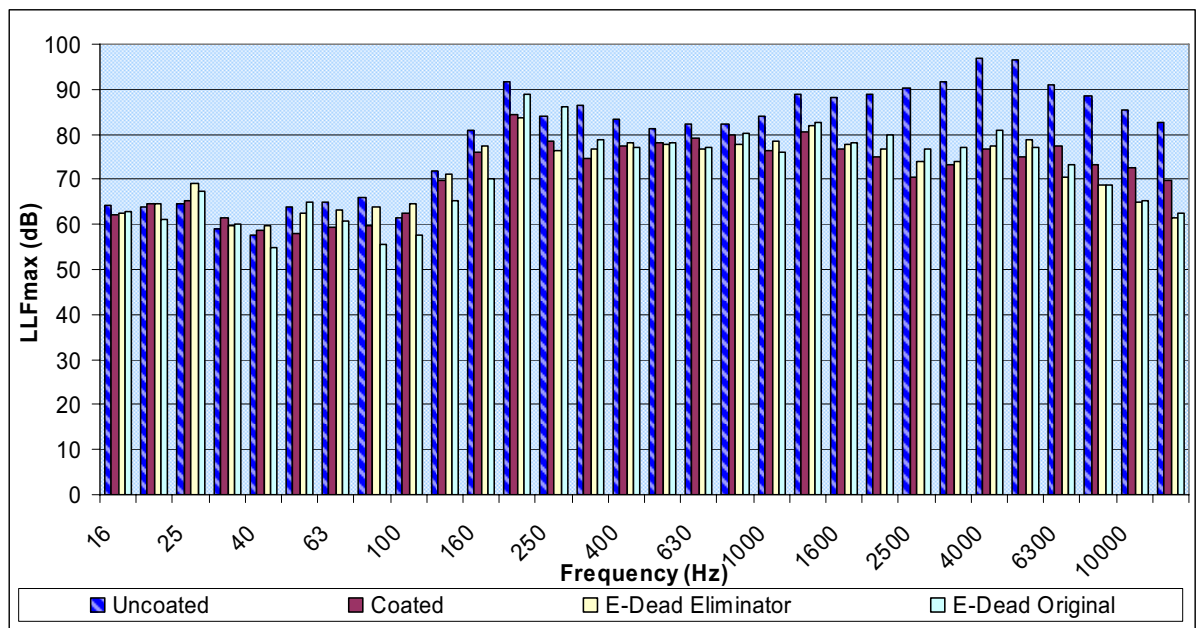


Figure 4.17. Spectra for the falling weight test comparing uncoated aluminium to a coated aluminium panel; aluminium with Σ -Dead Eliminator applied and with Σ -Dead Original applied.

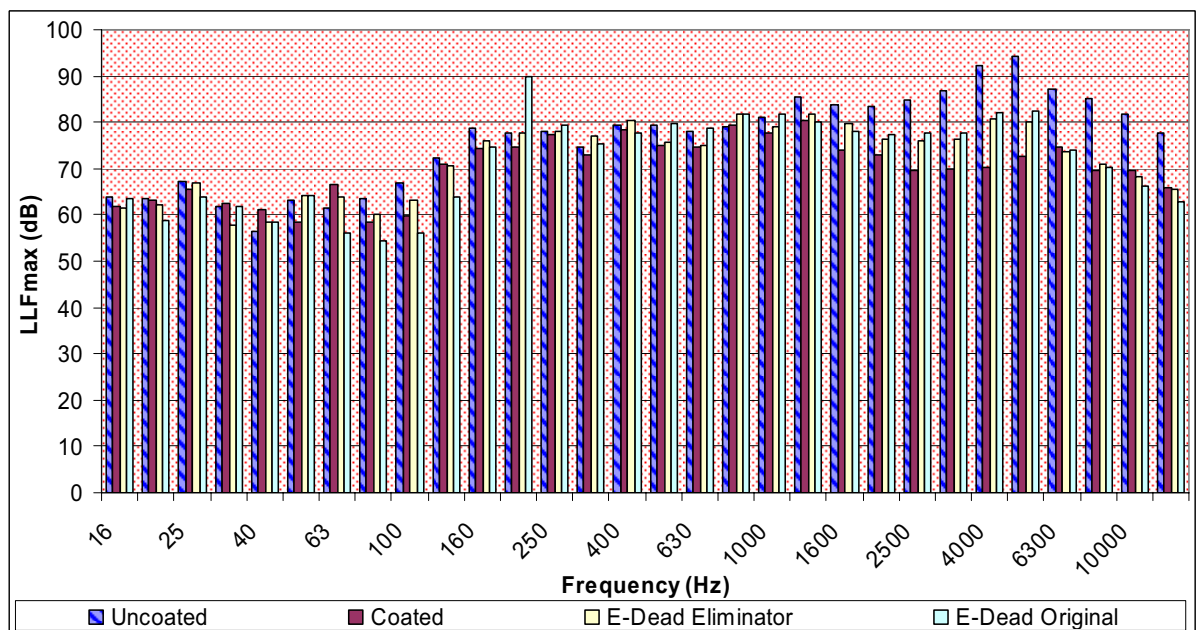


Figure 4.18. Spectra for the falling weight test comparing uncoated mild steel to coated mild steel panel; mild steel with Σ -Dead Eliminator applied and with Σ -Dead Original applied.

4.5.2 Investigation of the possible influence of different clamping loads on the excitation of the panels

The influence of the application of different clamping loads on the sound generated by the pendulum weight impacting on the test panels was investigated. This was done by applying increasingly higher torques to the four clamps that sandwiched the test panels between the fixed vertical frame, and the demountable frame of the pendulum apparatus. The apparatus and the relevant attachments are illustrated in Figures 4.19 to 4.22 and are also described in Appendix II.3.2.

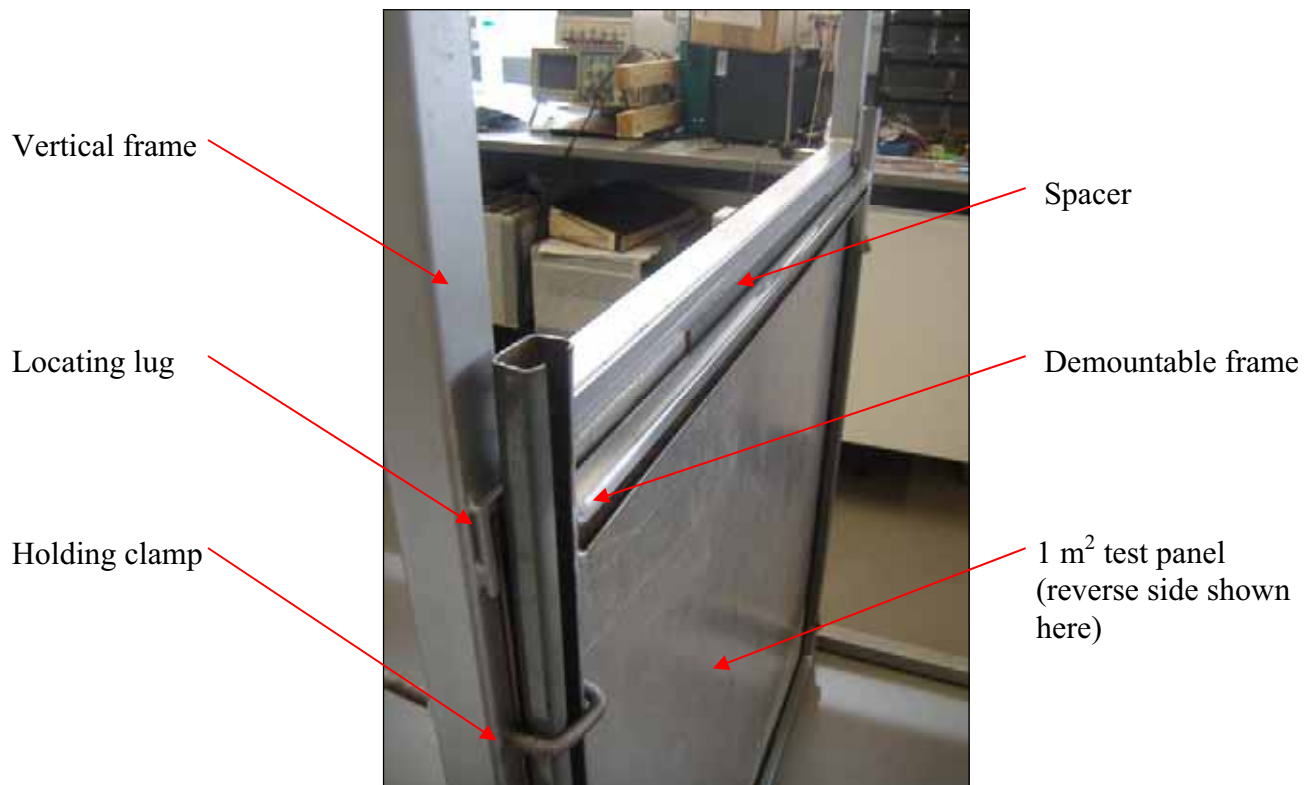


Figure 4.19. Photograph showing a test panel sandwiched between the steel vertical support frame and the demountable frame. The bolted clamps and the spacers are also illustrated.

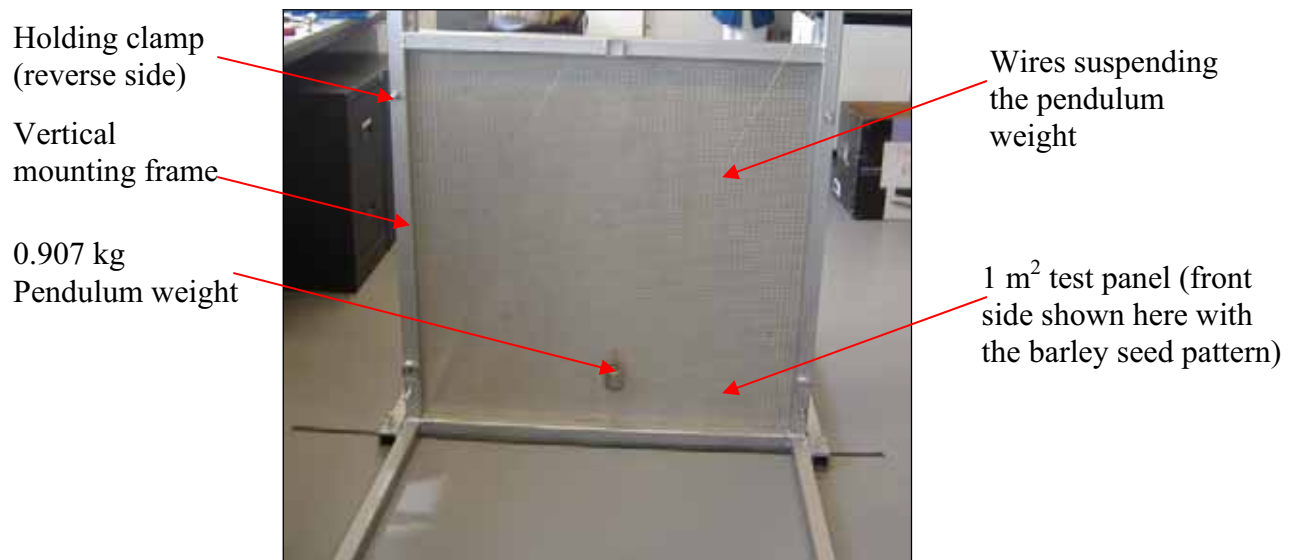


Figure 4.20. Photograph showing the suspended pendulum weight with the barley seed patterned aluminium panel facing the plumb weight.



Figure 4.21. Photograph showing application of the torque wrench to the fixing clamps which are fabricated from threaded bars.



Figure 4.22. Photograph showing the clamp which comprises a threaded shaped rod to clasp the holding frames and the panel together.

Noise impact tests were carried out on three different panels; (a) an uncoated aluminium panel (b) an uncoated mild steel panel and (c) a coated mild steel panel. Three different torques settings of increasing magnitude were applied to the four clamps holding the panels to the frames of the apparatus. The panels were each repeatedly impacted (ten times) by the pendulum and the average logarithmic LAF_{max} for each of the three tests were calculated. The clamping forces were then plotted and correlated against the impact sounds, as reported in Table 4.6 and Figure 4.23.

Table 4.6. Description of panels tested and the sounds generated by application of different torque loads to the holding clamps.

Panel	Average LAF_{max} resulting from the different torques applied to the clamps		
	12 Nm	16 Nm	20 Nm
Aluminium uncoated	80.9 dB(A)	80.1 dB(A)	80.3 dB(A)
Mild Steel uncoated	84.1 dB(A)	84.2 dB(A)	83.5 dB(A)
Mild Steel coated	72.5 dB(A)	74.1 dB(A)	73.5 dB(A)

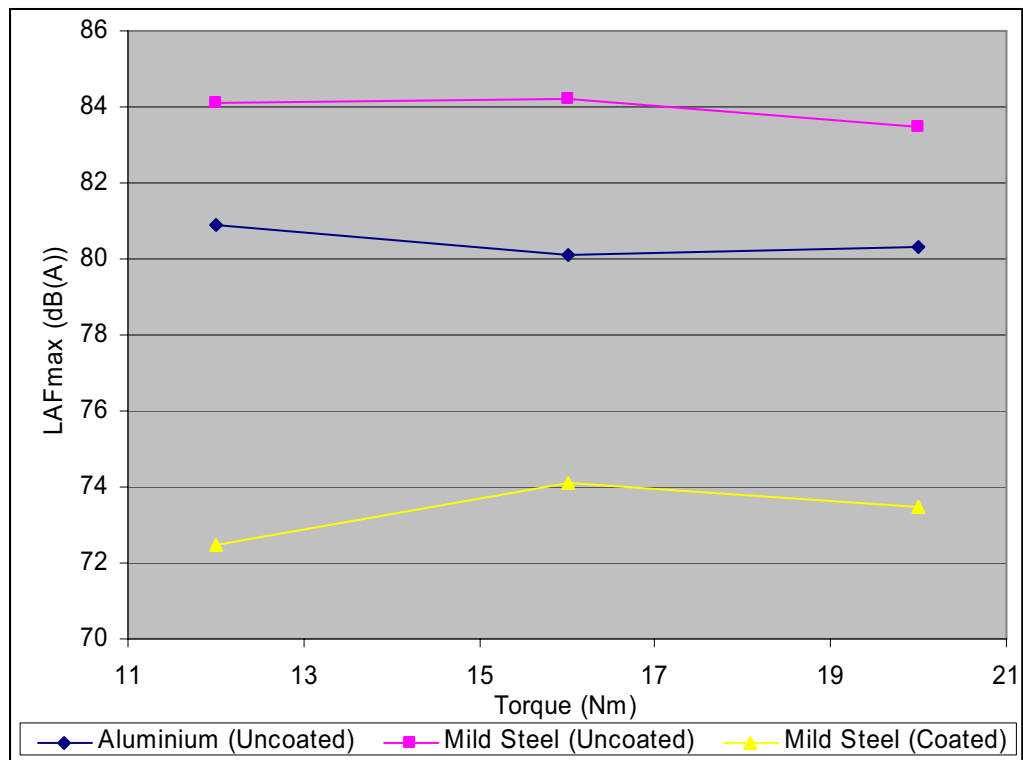


Figure 4.23. Graph showing the average LAF_{max} levels generated during testing at the three different torque settings applied to the 1 m² metal plates.

The application of increasing torque loads to the holding clamps had no significant impact on the sound generated by the impacts of the pendulum on the panels. The characteristics of the frequency spectra were also unaffected, as shown in Figure 4.24.

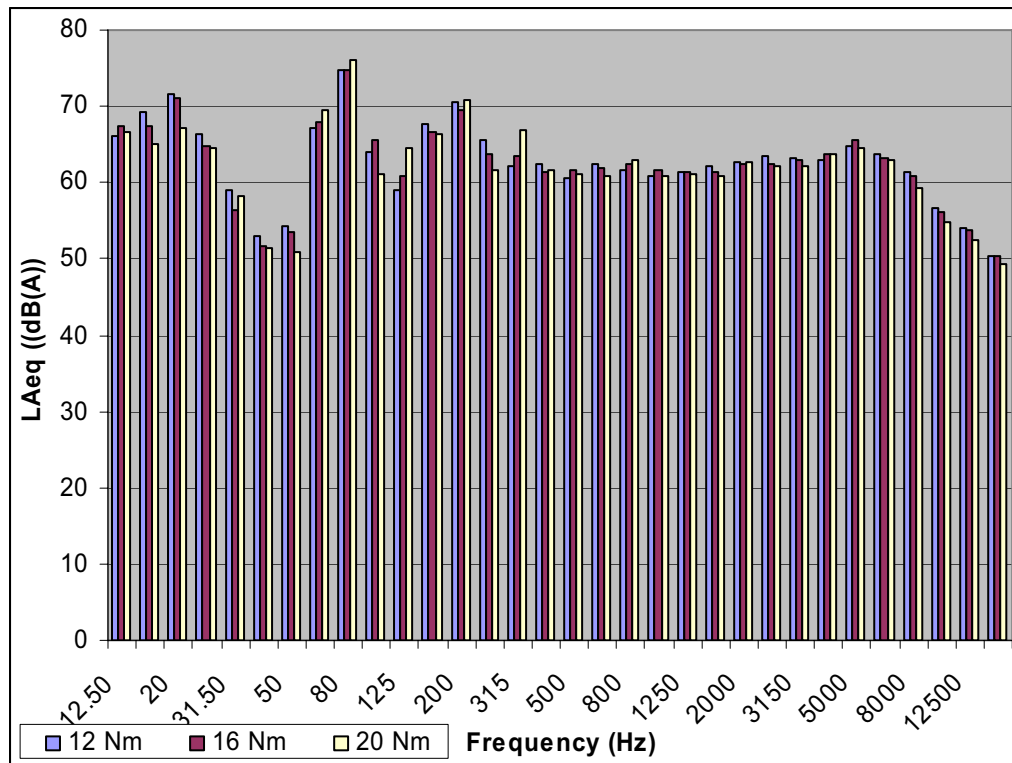


Figure 4.24. Spectra for an uncoated aluminium plate showing the application of different torque loads (12 Nm, 16 Nm and 20 Nm) to the clamping frames.

The results may be explained by the fact that the panels were made of dense metal materials and were also relatively thick in cross-section, 2 mm in the case of the aluminium plate and 3 mm in the case of the mild steel plate and could not be easily vibrated. The clamping forces did not put the panels in tension and should not for example, be compared with the situation arising in the case of a clamped vibrating thin-skinned diaphragm of a musical instrument such as a drum. It was therefore concluded that the impact noises arising from metal flooring panels which were firmly secured to the floor of a HGV trailer units, are not unduly affected by the clamping forces applied. It should be noted that the pendulum test results reported in the previous sections involved the application of a hand-tight torque of approximately 10Nm to the fixing clamps which approximates the torque applied by a HGV vehicle body builder when fixing flooring panels, as referred to in section 4.3.2.2.

4.6. Field trials at test site: Evaluation of the acoustic coating on board an HGV trailer.

4.6.1. Introduction

The aim of the trial was to evaluate on board an HGV trailer unit, the effectiveness of the new coating formulation which was pre-screened in the laboratory. The new acoustic coating was applied to 1 m² panels of aluminium and mild steel substrates. The candidate panels were placed inside a stationary HGV trailer and the impacts that typically occur during deliveries were simulated by means of the portable falling weight and the pendulum test rigs as used in the laboratory.

The tests were devised to simulate the sound radiated by objects dropping or impacting with the floor and wall of a HGV trailer unit. As stated in Chapter 3, the major impacts during deliveries were observed to be caused by the wheels of the roll-cages transiting the trailer floor and by collisions with the kick-walls. The tests were carried out on board an HGV trailer unit on the 22nd January 2007 at the test site which is the distribution centre for a large chain of supermarkets and convenience stores.

The following substrates were tested; (1) GRP uncoated panel, (2) GRP coated panel (3) aluminium uncoated trailer floor (4) aluminium coated panel (5) mild steel uncoated tail-lift platform (6) mild steel coated panel.

The falling weight test was applied to the aluminium and steel panels because these suffer vertical impacts during deliveries and are transited by the wheels of the roll-cages.

The pendulum test was applied only to the GRP panel because this material, as used on the trailer walls above the aluminium kick-walls, may suffer side impacts during deliveries.

The sound level readings from impacting the coated and uncoated substrates with the 0.907 kg weight were measured by placing the B&K microphone on a tripod at a

distance of 3.5 meters at right angles from the side of the trailer. The sounds transmitted through the walls at different positions within the trailer unit were recorded as shown in Figure 4.19 below. The panels were moved to three positions, 1, 2 and 3 within the 13.2 meter length of the trailer body (towards the front, the middle and near the rear) and the impact sounds were recorded in LAF_{max} .

Noise measurements were also taken of impacts to the mild steel tail gate platform by sitting the microphone 3.5 meters away from the rear doors of the trailer at a height of 1.2 meters in accordance with BS 4142. The locations of the noise meter are shown in Figure 4.25. The background noise was typically 61 LA_{eq} but a max of 70 LAF_{max} was experienced when there was passing traffic or an HGV engine was running in the background.

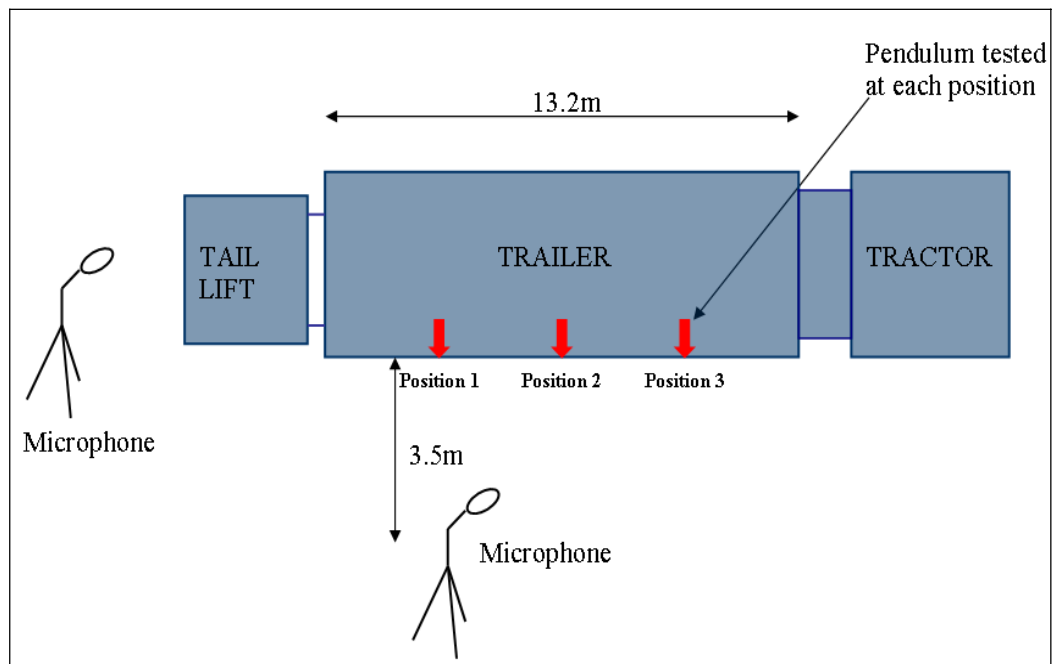


Figure 4.25. Schematic showing the positions of the panels and the sound meter at the distribution depot test site on board the HGV trailer (plan-view).



Figure 4.26. Photograph of the inside of a HGV trailer showing uncoated chequered aluminium flooring.



Figure 4.27. Photograph of tail-lift showing the coating applied to the mild steel platform

4.6.2. GRP evaluation using the pendulum test

The pendulum test was applied only to the GRP uncoated and coated panels because the GRP trailer walls suffer some side-ways impacts during deliveries. In practice it was observed that most sideways impacts are absorbed by the aluminium kick-walls which protect the lower 30 mm of the trailer walls as illustrated in Figure 4.26.

The coated and uncoated GRP panels were pushed up hard against the inside wall of the trailer at three different positions within the trailer body as shown in Figure 4.25. Readings were then taken of the sound transmitted through the trailer wall on the striking of the panel at a point 150 mm. above the floor by the 0.907 kg pendulum weight. This procedure was repeated 10 times and the logarithmic averages were calculated.

The noise from the first position at the rear of the trailer was measured by placing the microphone 3.5 metres away from the rear doors. The noise from the second and third positions was measured by placing the microphone at right angles to the trailer body opposite these positions and mounted at a distance of 3.5 meters away from the side of the truck.

The pendulum test noise readings for the uncoated and coated GRP panels located at the three different positions within the trailer are summarised in Table 4.7 and more detailed readings are given in Appendix II.2 and II.3.

Table 4.7 Logarithmic averages of the pendulum tests in dB(A) on uncoated and coated GRP on board the HGV trailer

Substrate	Position 1	Position 2	Position 3
Impacts	LAF _{max}	LAF _{max}	LAF _{max}
GRP uncoated	75.1	75.0	76.6
GRP coated	75.0	74.1	74.1
Reductions	0.1	0.9	2.5

No significant noise reductions were recorded at the test site in the case of the coated GRP panel in contrast with the very significant reduction of 12.2 dB reported earlier for the laboratory tests. The difference between the laboratory and this field trial results may have been due to the fact that the coated GRP panel could not be secured tightly to the side wall of the trailer and was therefore free to resonate. It was not possible to dampen the GRP panel by clamping it more securely due to irregularities in the trailer wall. Echoes within the trailer body were also a factor. In contrast the panels were held with similar clamping forces during the laboratory trials.

In order to compare how noise was attenuated across the frequency spectrum a number of spectra were generated. Figure 4.28 gives a comparison for coated and uncoated panels using the pendulum test sited at position 1 on the HGV trailer.

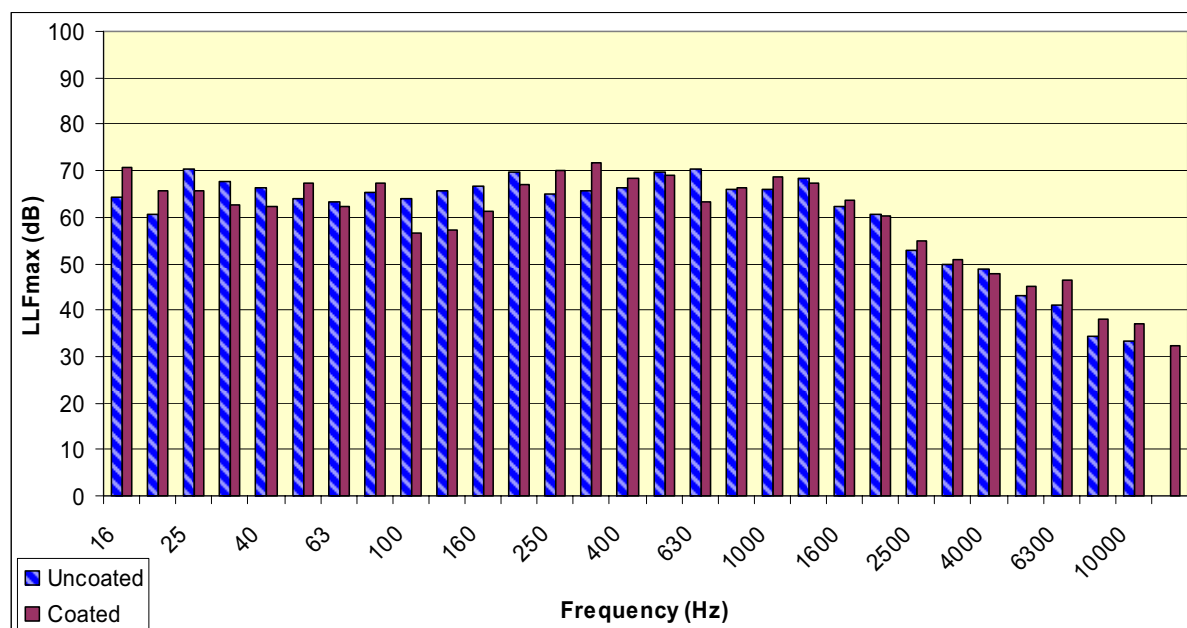


Figure 4.28. Comparison of spectra for uncoated and coated GRP panels tested with the pendulum at position 1 within the HGV trailer.

It was found that the application of the acoustic coating to a GRP 1 m² test panel did not significantly reduce the noise across the frequency range in any of the three positions where testing was carried out. Greater attenuation might have been recorded had the whole inside area of the GRP trailer side-walls been acoustically coated and the coating tested as an integral part of the HGV trailer walls. This was seen however as an impractical option in terms of expense and effectiveness because in fleet use it was observed that the aluminium 30mm high kick-walls absorb most of the side impacts caused by the roll-cages and it would therefore suffice to apply the coating only to the kick-walls.

4.6.3. Sound evaluation for aluminium using the falling weight test on the HGV trailer floor

The falling weight tests were applied to the aluminium and mild steel panels because this simulated the typical impacts caused by rollcages and locking bars being manipulated across the trailer floor and tail-lift platform. The test was applied to uncoated aluminium by directly impacting the floor of the HGV trailer and to coated aluminium, by laying a coated panel down on top of the trailer floor. Coated and uncoated mild steel panels were also similarly tested by laying a coated panel down on top of the tail-gate platform.

To simulate vertical impacts on uncoated aluminium, the weight was dropped directly onto the uncoated aluminium trailer floor (from a height of 150 mm at a distance of 0.50 meters away from the external wall) at three different positions inside the trailer, rear, middle and front as illustrated in Figure 4.25. Readings were taken in the outdoors at the rear of the trailer and at right angles to the trailer wall from a distance of 3.5 meters at the middle and front positions.

To simulate impacts on coated aluminium, the falling weight was dropped repeatedly onto the middle of a coated 1 m² panel placed inside the trailer. The coated panel was positioned firmly on the floor at the rear of the trailer and subsequently at the middle and front positions inside the trailer. The edge of the panel was abutted and secured against the inside trailer wall.

Table 4.8 compares the average sound levels recorded for a series of 10 impacts of the falling weight directly onto the uncoated aluminium HGV trailer floor with the impacts onto the coated aluminium panel at similar positions inside the trailer body. The test results are summarised in Table 4.8 and recorded in more detailed in Appendix II.5.

Table 4.8. Impacts on coated and uncoated Al substrates compared.

Al Substrates	Position 1	Position 2	Position 3
Impact Noise	LAF _{max}	LAF _{max}	LAF _{max}
Al floor, uncoated	90.9	87.4	92.2
Coated Al panel	84.0	85.3	84.9
Reductions	6.9	2.1	7.3
Average Reduction (Arithmetic)	5.4 dB(A)		

The logarithmic average reduction achieved by the application of the coating was 5.4 dB(A). Ideally the total 13.2 x 3.5 meter square HGV trailer floor area might have been fully coated and the falling weight test results compared with the results from an uncoated floor, but this was not possible due to the time and cost constraints imposed by the fleet operator.

In order to compare the test results in the field trial at the test site with those obtained in the laboratory, a comparison is made in Figure 4.29 between the spectra recorded on board the HGV trailer with those recorded in the laboratory for the falling weight test as applied to the same coated aluminium panel.

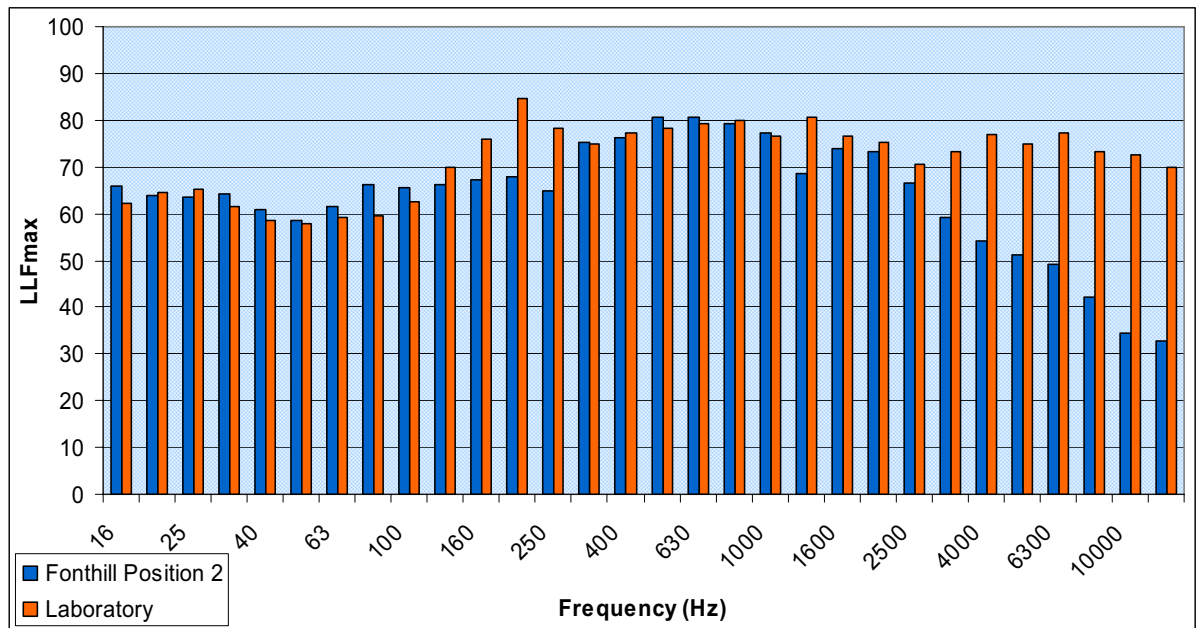


Figure 4.29. Comparison of falling weight spectra for a coated aluminium panel tested in the laboratory and with a spectra for position 2 at the test site.

Again as seen in Figures 4.6, 4.7, 4.15 and 4.16 the characteristic aluminium resonance at 250 Hz can be also be seen in Figure 2.29.

It can be seen that very significant attenuation was recorded at the test site at frequencies above 1,600 Hz, which was not the case in the laboratory. This difference may be explained because the higher frequencies emanating from position 2 inside the trailer were absorbed by the thick GRP walls, whereas in the laboratory these frequencies would have been reflected by the dense concrete walls within a confined space. The GRP walls therefore may have given some additional transmission loss effects at the higher frequencies. For example, if one compares the expected transmission losses through a 6.35 mm thick plywood wall as being roughly similar to the transmissions through a GRP trailer wall, an attenuation of 15 dB at 250 Hz and 25 dB at 8,000 Hz. might be expected (Bell and Bell, 1994, p.219). The higher radiation area of the trailer may have also made a difference.

4.6.3.1. Mild steel evaluation using the falling weight test on the tail lift platform

The falling weight test was repeated on the mild steel tail lift platform, as illustrated in Figure 4.27. The coated mild steel panel was placed in the centre of the tail-lift platform and the weight was dropped repeatedly onto its centre from a height of 150

mm. The test was repeated on a coated panel placed in the same position. The results are summarised in Table 4.9:

Table 4.9. Impact noise on coated and uncoated mild steel panels

Uncoated Panel	Coated Panel	Reduction dB
95.1	86.1	9.0

The logarithmic average noise reduction recorded was 9.0 dB.

A comparison was made between the spectra obtained in the laboratory with those recorded in the test site for the coated mild steel panel; these are illustrated in Figure 4.30.

It can be seen from Figure 4.30 that the attenuation recorded in the test site was greatest between 100 Hz and 250 Hz and at the higher frequencies above 4000 Hz unlike the laboratory test where the higher frequencies were less affected. The greater attenuation at the higher frequencies recorded in the test site may be explained by reverberation occurring in the confined space of the laboratory building when none was evident in the open logistics yard at the test site. The higher frequencies could dissipate readily in the open space at the test site.

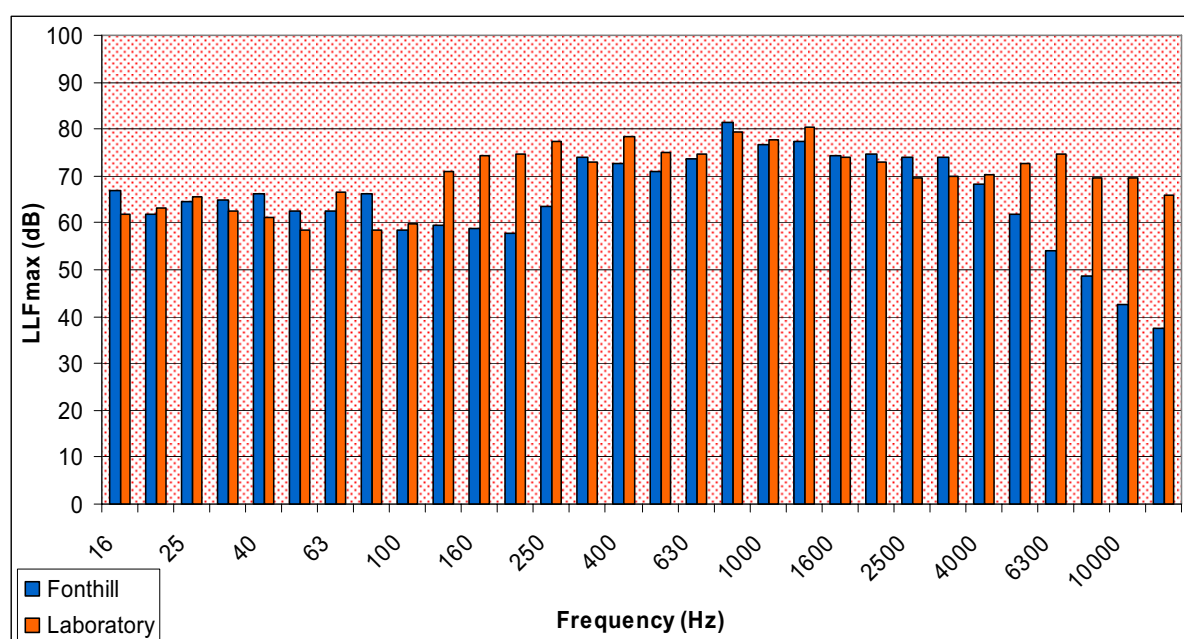


Figure 4.30. Comparison of the spectra for a mild steel coated panel tested with the falling weight in the laboratory with placement on the HGV tail lift platform.

A comparison can also be made between the spectra for the coated aluminium panel taken at the test site as shown in Figure 4.29, where attenuation occurred earlier at 1,600 Hz and the mild steel panel where attenuation occurred at the higher frequencies of 4,000 Hz and above, as indicated in Figure 4.30. This may be explained by transmission losses taking place through the GRP trailer walls in the case of the tests on the aluminium panel as illustrated in Figure 4.25, unlike the steel panel which was tested in the open on the tail-lift platform attached to the rear of the HGV trailer.

4.7. Acoustic coating durability tests

The carousel test rig developed to evaluate the application of “hush kits” to the roll cages as described in chapter 5 was adapted to measure the durability of the acoustic coating. These durability tests are summarised in the Appendix II.6.2 to II.6.6. However these experiments are not described in detail as the question of durability in fleet operation is secondary to the focus of this particular research which is on noise suppression.

The simulation of wear and tear in fleet service on the carousel test rig indicated a probable life of from 9 - 10 months for the acoustic coating when applied to the floor of the HGV trailer unit. This was calculated to be the equivalent to 20,000 cycles of a partly loaded roll-cage transiting across a coated aluminium or mild steel panel. The wear tests assumed that a loaded roll-cage passed over the same point twice a day, five days a week at ambient temperature. This wear test did not however take into account the possible effects of the cleaning of the trailer floor with food-grade alkaline detergent or of a refrigerated environment inside the trailer as happens in the field.

A dial gauge fitted with a flat probe was used to measure the thicknesses of the coating on the highest points on the ridges of the chequered plated teeth because this is where most abrasion is caused by the passage of the roll-cage wheels. The readings were repeated using a micrometer and only a small variation of from 0.16 % to 0.79 % between the dial gauge readings and micrometer readings was recorded.

The viscoelastic damping layer of the acoustic formulation was protected by a robust polyester top coat layer which was abraded to begin to reveal the black viscoelastic

damping layer following up to 20,000 cycles on the carousel. This indicated that a thicker or harder polyester top coat would be necessary to ensure a longer in-service life of up to two years as expected by the fleet operator and this possibility will be investigated by General Paints Ltd. However the application of a more robust top coat ($> 150 \mu\text{m}$) above the viscoelastic water-based middle layer and primer, may compromise the acoustic effectiveness of the overall three layer formulation ($500 \mu\text{m}$ in total cross section). This consideration merits further investigation.

4.8. Conclusion

The hypothesis that the application of a damping material in the form of an acoustic coating to the substrates used on the floors and tail-lift platforms of a HGV trailer was justified in terms of the noise reductions achieved.

A methodology was developed which comprised a series of pre-screening experiments in the laboratory, leading to larger scale trials on coated panels on board an HGV trailer unit and tail-lift platform. These experiments generated a substantial body of data which was analysed to assess the performance of the acoustic coating when applied to the different substrates, namely aluminium, mild steel and GRP. There was a focus on how the coating attenuated the impact noises across the higher signature frequencies which were characteristic of the manipulation of roll-cages and ancillaries, as reported in Chapter 3.

The acoustic performance of the new coating compared very favourably with the selected commercially available damping materials which were also tested and indicated that a targeted noise reduction of at least 5 dB(A) could be achieved, particularly across the higher signature frequencies which are typical of the manipulation of roll-cages and ancillaries. While the noise attenuation recorded under the controlled laboratory conditions for the new coating was significantly greater than that recorded out in the open at the retail depot test site on board the HGV trailer unit, the latter results were still impressive and showed a logarithmic average reduction of

5.4 dB(A) in the case of the aluminium panels and 9.0 dB(A) in the case of the mild steel.

Any recommendation to apply the coating to cover the whole floor area of an HGV should however, await the development of a more robust formulation which could withstand up to two years in fleet service. This may necessitate the application of a thicker or harder polyester top coat and it remains to be seen whether this would diminish the damping properties of the overall three layer formulation which comprises of a primer, a viscoelastic middle layer and a top layer.

While the coating was effective in damping the aluminium and mild steel panels, it was not suitable or effective for application to GRP.

Comparisons between the frequency spectra for the different substrates and for the different tests (the falling weight and pendulum tests) gave worthwhile results and showed several anomalies which are described in the text. The results were explained with reference to the conditions and background noise applying at the times of the different tests in the laboratory and in the field on board the HGV trailer unit.

The anomalies identified included a characteristic resonance appearing at 250 Hz when aluminium was impacted, the coating showing greater attenuation at a lower frequency of 1,600 Hz for mild steel and at a higher frequency of 2,500 Hz and greater for aluminium. The decay times for the impacted aluminium and mild steel panels were found to be substantially reduced by a factor of four when measured on an oscilloscope and these experiments confirmed the damping effectiveness of the coating when measured on the B&K sound meter. It was found that the application of increasingly strong clamping forces to the test panels under laboratory conditions had no significant influence on the sound or frequencies emitted. It was evident that the relatively dense and thick metal panels do not behave like a thin diaphragm such as the skin of a drum under tension.

Because of the high noise levels of up to 80 dB recorded during deliveries to shops when aluminium and steel HGV trailer floors and tail-lift platforms are impacted by roll-cages as described in Chapter 3, it is evident that the application of an acoustic

coating alone would not be sufficient to reduce the noise levels on the streets to limits approaching 66 dB; this limit being equivalent to that recommended in the Netherlands (PEAK, 2007). A holistic approach involving the attenuation of the noises at source will be needed to meet any limits likely to be imposed by Dublin City Council in compliance with the EC Noise Directive, and will necessitate the application of damping hush-kits to the roll-cages as described in Chapter 5 and modifications to other ancillaries such as the refrigeration units (European Commission, 2002).

CHAPTER 5. ATTENUATING ROLL CAGE NOISE

5.0. Introduction

During field trials described in Chapter 3, it was discovered that one of the key contributing factors to nuisance noise was generated by the manipulation and rattling of the roll cages. The purpose of the research was to develop an acoustic kit that could be retro-fitted to a standard steel roll cage. Due to the large number (200,000) of roll cages currently in service around the country it would not be commercially viable to replace the existing stock in the short-term with a dedicated “silent” new design.

The challenge was to develop an inexpensive solution in the form of a hush-kit which could be readily retro-fitted during the normal servicing of the roll-cages. A typical HGV trailer can hold up to 48 loaded roll cages. The distributors indicated that they might entertain an additional cost penalty of 10 – 15% of the original cost of a standard rollcage to retro-fit a hush-kit in order to ensure continuing access to the city at night and to comply with pending noise regulations.

The fleet operator indicated that their requirements for a hush-kit solution would include -

- (a) the effective attenuation of the peak noises caused by the handling of roll-cages
- (b) the need for an inexpensive hush-kit package that could be easily fitted during the regular servicing of the cages
- (c) durability and the ability to withstand wear and tear and low temperatures during the carriage of chilled foods.

The alternative option of developing a completely new non-standard all-polymer roll-cage was pursued by Sturdy Products Ltd., a partner in the Innovation partnership programme (Byrne, Finlay and Grimes, 2007). Due to the high production costs involved, an all-polymer replacement for the conventional steel cages was unlikely to

find early acceptance by the fleet operators, hence the focus was on an inexpensive retro-fit solution.

5.1. Focus on damping the vibrating and resonating surfaces

As in Chapter IV which describes the application of an acoustic coating to the metal floors of the HGV trailer unit, the priority again was to dampen the noise caused by the vibrating parts and components of the steel roll cage. As stated in Chapter 2 in respect of the research methodology, the literature suggests that the application of rubber and other viscoelastic materials is very effective for damping resonating surfaces in industrial machinery (Bell and Bell 1994, chapter 6; Smith, Peters and Owen, 1996, chapter 8).

Rubber strips, pieces of hose and viscoelastic adhesive strips were therefore selected for application to the steel frame and resonating components of the conventional roll-cage.

5.2. Methodology

The objective was to develop and to evaluate a low cost hush-kit and to design a special carousel test rig and a series of experiments to achieve this.

The carousel test rig was designed to mimic the typical movements of a roll cage during a delivery when the cage is pushed at a walking speed of 3km/h. In service a cage will be pushed over a variety of different surfaces such as the floor of the HGV trailer, the tail lift platform, road pavements and paths and kerb-sides. The carousel rig enabled the transits of empty and loaded cages over uneven surfaces to be simulated. The carousel was also designed to measure the durability of the new acoustic paint when applied to specimen samples of aluminium and mild steel panels.

The rotating test rig was similar to a small fairground carousel. The candidate roll cages remained stationary while the rotating surface was allowed to pass under the

wheels of the cage. The hydraulic motor driving the carousel was controlled at a constant speed so that the acoustic performance of different modifications to the roll-cages could be compared.

Because the roll cage was anchored in a stationary position, the B&K sound analyser could also be fixed in a position at a distance of 3.5 meters from the vibrating roll-cage and at a height of 1.2 meters above ground in accordance with BS 4142 (British Standards, 1997). This arrangement facilitated the observation and easy identification of the rattling components and vibrating surfaces of the roll-cage under test as the carousel surfaces passed underneath the wheels. This was seen as an easier arrangement than the alternative of pushing a roll-cage up and down along a fixed path at a constant speed. The carousel could be easily set up and timed to run automatically and the sound measurements recorded. Additional advantages of the carousel were the relatively low and un-intrusive background noise created by the hydraulic drive and the ease with which the rotating speed could be controlled.

5.2.1. Identification of the resonating parts

The resonating parts were identified and marked on the fixed roll cage by observing the carousel in motion. By adding different components to the hush kit it was possible to eliminate various rattles one at a time and to determine where best to apply the damping materials. The parts where damping applications were identified as being necessary are illustrated in Figure 5.1:

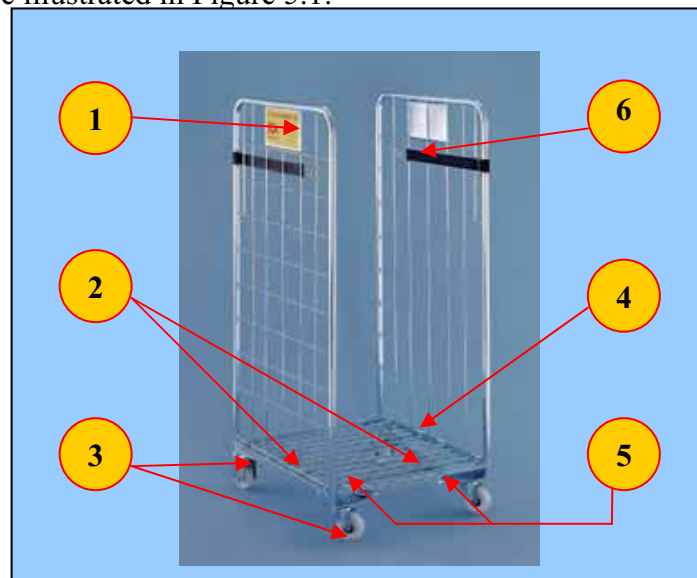


Figure 5.1. Photograph of vibrating roll-cage parts.

It was observed that noise was created by the empty and part loaded roll-cages when

- (a) cages are moved across the HGV trailer floor and tail-gate platform
- (b) cages are folded and nested and
- (c) when they collide with stationary cages, obstacles and walls.

The first scenario (a) was simulated by means of the carousel and the second and third scenarios, (b) and (c) were simulated by devising special nesting and collision tests.

5.2.2. Vibrating components while in motion

The components of the roll-cage which vibrate while in motion were observed and marked as the cage was shaken on the carousel. These components are shown in Figure 5.1 and comprised:

- (1) name plate affixed to lattice frame
- (2) the “A” frame
- (3) castors and wheels
- (4) folding floor
- (5) hinges of lattice uprights
- (6) securing straps and clasps

5.2.3. The nesting and folding of the cages

Roll cages were nested repeatedly to determine where the noise was generated. This was found to be caused by:

- (1) The sides of the roll cages colliding together.
- (2) The floor striking the side lattice-work when it was secured in the upright position before nesting.
- (3) The “A-frame” striking the side bars of the cage.
- (4) The folding of the sides of the cage across the castor knuckles (not shown in Figure 5.2).

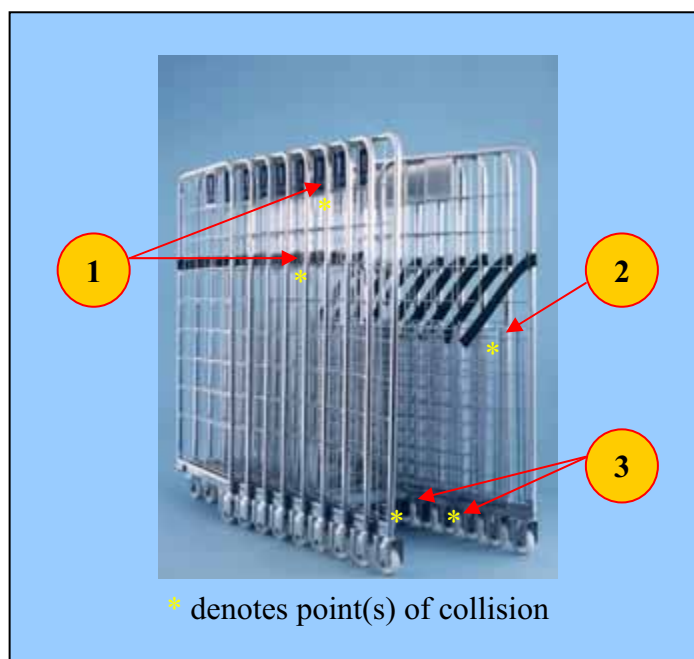


Figure 5.2. Photograph of components affected by nesting

The procedure for nesting of the cages involved folding the front hinged lattice uprights together across the front castor knuckles and then pushing the folded cage bodies tightly together. The floors and side lattice frames were hinged to the “A” frame to facilitate nesting and easy storage.

The parts which were impacted during nesting are illustrated in Figure 5.2. These were (1) the uprights for the lattice-work (2) the straps and clasps and (3) the front section of the “A” frame. Damping materials were applied to the parts identified and illustrated in Figure 5.2 and as described below in Table 5.1.

Table 5.1. Application of damping to parts affected by nesting

Affected Area	Material applied	Comments
1, 2 & 3	Hose	Hose was split along its length and attached to the lattice frame uprights to act as a barrier between colliding components.
1, 2 & 3	Band-aids	Stickers with a rubber or elastic damping material with an adhesive backing were applied to the contact areas.
1, 2 & 3	Stoppers	Rubber bungs were clipped on to the frame sections to reduce the impacts from the cages colliding. Strips of rubber with adhesive backing were also applied.
Corner top protection	Tailored pieces	Tailored rubber pieces were glued to the vulnerable corners of the frames

A selection of rubber and other materials was made using the Radionics catalogue (Radionics, 2007) as described in Appendix III.6 and III.7.

5.2.4. The carousel test rig and demountable arm.

As mentioned in chapter 2.3, a carousel test rig was specially designed to:

- (a) help identify the vibrating parts of the roll-cage.
- (b) assess the effectiveness of the hush-kit applications.
- (c) test the durability of the new acoustic coating described in Chapter 4.

Other options for simulating the behaviour of the roll-cages during delivery operations were also considered. One was to manually push the roll-cages along a measured path at walking pace; the second was to release the roll-cages down an inclined ramp; the third was to mount the roll-cages on a vibrating platform. None of these options were seen to be as easy to control as the rotating carousel apparatus.

A disadvantage of the carousel was that the inner roll-cage wheels transited a much smaller arc than the outer wheels when the carousel was in rotation. Space constraints at the DIT Bolton St. HGV workshop did not allow for a larger diameter carousel platform greater than 2.5 meters to be installed.



Figure 5.3. Photograph of carousel with roll-cage under test

A photograph of the carousel is shown in Figure 5.3 and plan view of the rig is described in Figure 5.4.

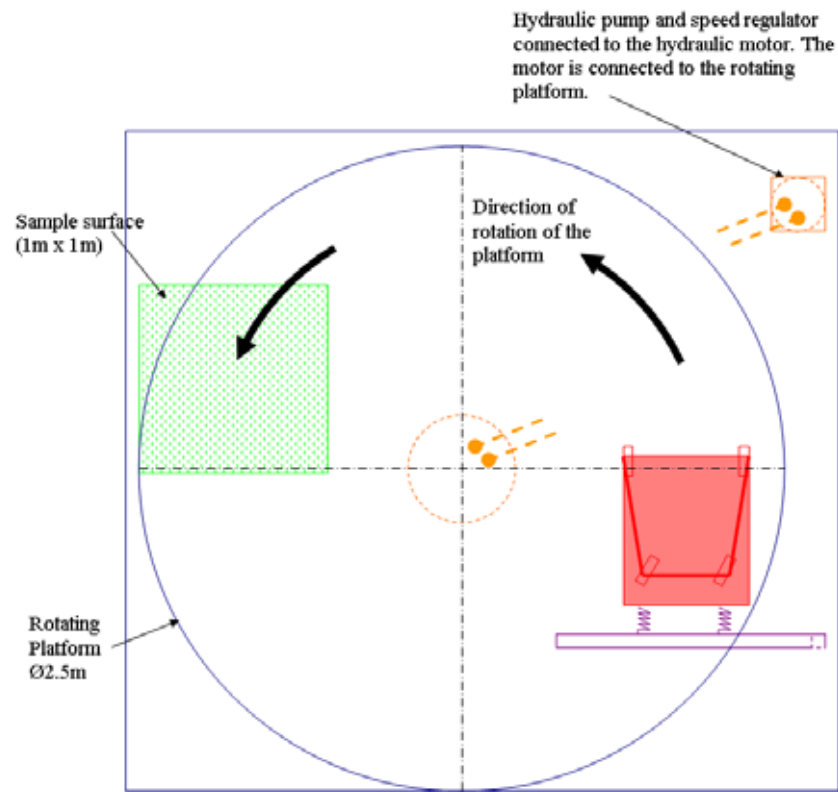


Figure 5.4. Plan view of the carousel test rig

The hydraulic motor was powered by an external motor and pump assembly which was acoustically screened at a site some 5 meters away from the carousel requiring long lengths of hydraulic hose to be run between the pump assembly-site to the hydraulic motor located underneath the carousel. The speed of the hydraulic motor was controlled at the pump assembly-site.

In order to examine more closely the noise generated by modifications to the castor wheel assemblies, a hinged arm fitted with a weighted tray and attached to an overhanging bar was fabricated. In this way different proprietary castors and wheels could be compared and modifications to conventional castors could be evaluated. The arm attachment arrangement is illustrated in Figure 5.5.

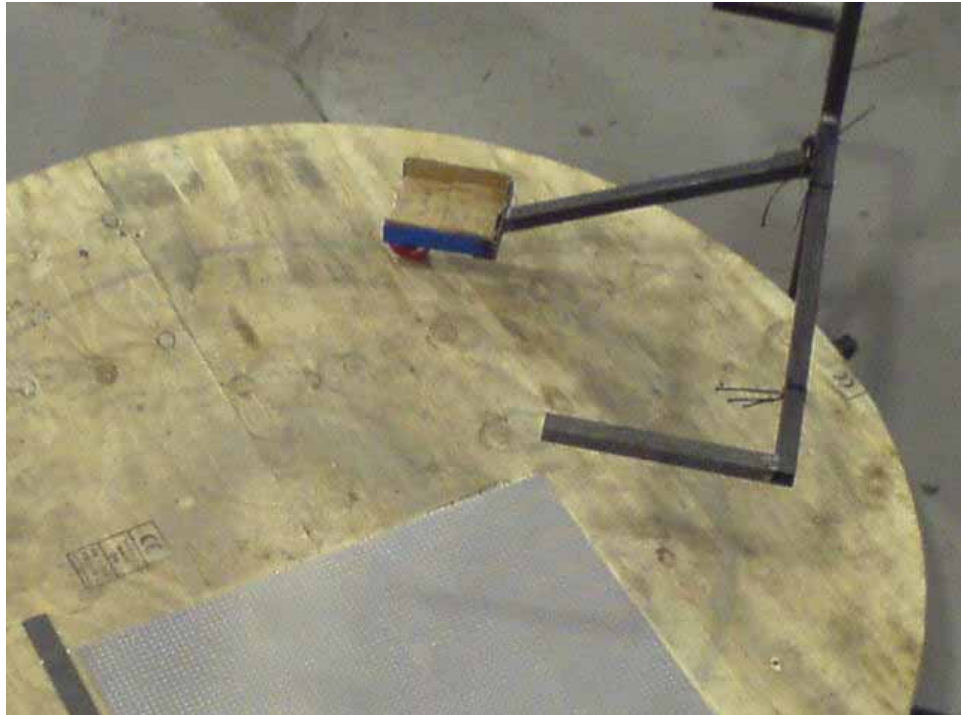


Figure 5.5. Photograph of the arm and tray assembly attached to the support beam on the carousel test rig

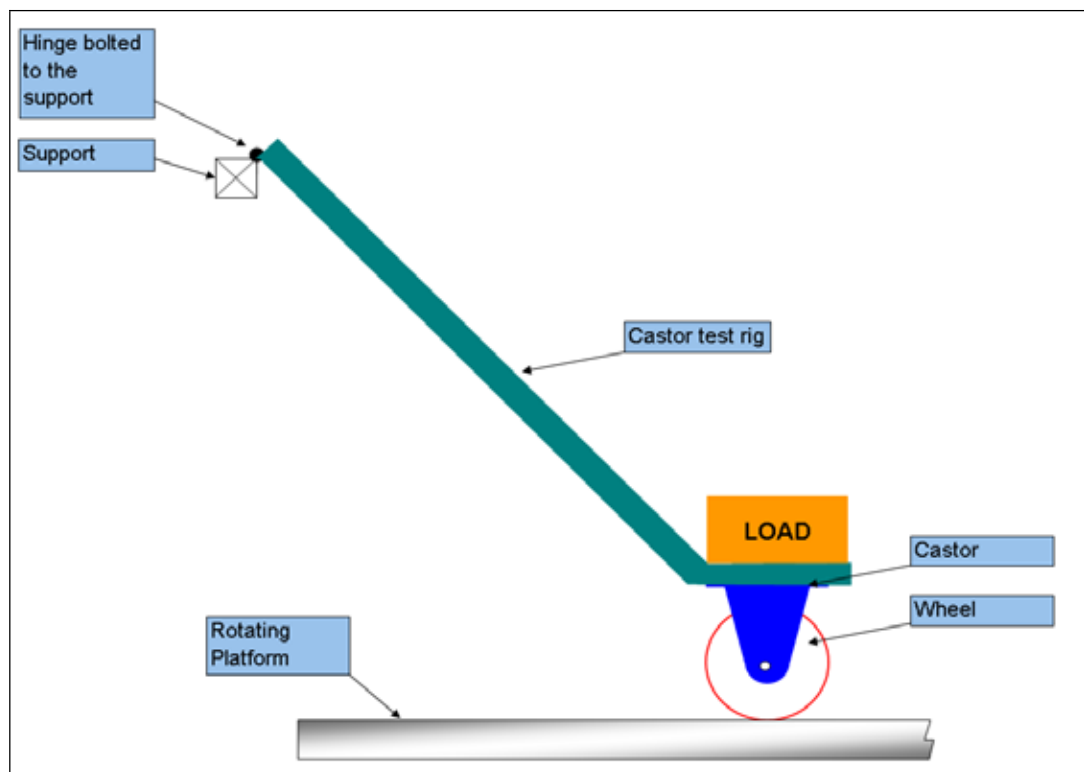


Figure 5.6. Sketch of the arm assembly attached to the carousel in order to test and compare the noise from different wheels and castors and to assess the addition of modifications.

5.2.5. Modifications to castors and wheels

Having identified the resonating parts of the roll-cage, a series of tests were conducted to assess the effectiveness of the application of damping materials to the different parts. In the case of the wheels and castors, the different types of damping adjustments which were examined are listed below in Table 5.2. A load of 16 kg was placed into the tray on the castor plate and since the loading arm weighed 6 kg the total weight on the wheel was 22 kg.

Different modifications of the castor and wheel units were made and these were attached to the suspended arm. A weight of 16 kg was then loaded onto the tray and the carousel was rotated at walking speed of 3 km/h and noise recordings were made for a period of 2 minutes. The noise reductions achieved were calculated by comparison with the noise from a standard unmodified castor unit which gave an average LA_{eq} reading of 65.1 dB(A).

Table 5.2. Noise reductions achieved by the application of damping modifications to the castor unit and wheel

Assessment of different modifications	Noise dB(A) recorded	Reduction dB(A)
Benchmarked against unmodified front castor unit	65.1	0
2 grooves machined on standard swivel castor wheel	62.3	2.8
3mm rubber membrane between the castor & frame	63.2	1.9
3mm rubber membrane on top of the mounting plate	61.3	3.8
10mm rubber membrane between the castor & frame	61.8	3.3
10mm rubber membrane on top of the castor & 3mm rubber membrane above the mounting plate of the test rig	60.9	4.2
"e-dead eliminator" ring fitted to one side of the wheel	65.2	-0.1
o-rings fitted into the 2 machined grooves of the wheel	58.9	6.2

From Table 5.2 it can be seen that the most significant noise attenuation of 6.2 dB(A) was achieved by attaching two rubber o-rings to the standard wheel. Two special grooves were machined into the rolling surface of the front hard plastic wheel to secure the o-rings in place. The value of -0.1 dB(A) reported for the fitting of the e-dead eliminator to a wheel was not regarded as acoustically significant.

The next best reduction of 4.2 dB(A) was achieved by isolating the bolt that joins the castor to the frame of the roll cage by means of a 3mm. rubber membrane. This prevented vibrations from passing from the castor to the frame of the roll-cage.

A selection of commercially available “soft” wheels was tested as described in Appendix III.1. While these softer wheels created less noise than the standard wheels, it was evident from an examination of the technical brochures that these softer wheels would not be capable of sustaining the heavy weights of up to 200 kg that are often loaded onto roll-cages in fleet service. Soft rubber wheels develop flats-spots if left standing under a heavy load for any length of time (Musgraves, 2007). For this reason it was decided not to try to replace the standard hard plastic wheels and to see whether they could be modified by the addition of rubber o-rings, which as described earlier in Table 5.2, gave satisfactory noise reductions of 6.2 dB(A).

5.2.6. Folding and dropping of the floor

When a roll cage is opened for loading, the floor is held in a vertical position, the sides are pushed out and the floor is dropped onto the A-frame creating a loud banging noise. To mitigate this, rubber bungs were placed on the uprights of the frame to absorb the sound when the floor was folded up and strips of rubber were also placed along the tops of the A-frame to dampen the noise of the floor crashing down upon it.

5.2.7. Closing and opening of sides

The opening and closing of the sides of the roll cages during nesting was observed to create loud impact noises. The parts and components making contact were marked out. The areas which were marked and modified with rubber stoppers and damping materials are illustrated below in Figure 5.7. Rubber stoppers were added to the inside edges of the roll cage body to dampen the impact of the A-frame collisions.



Figure 5.7. Photograph of rubber stoppers fitted to the inside surfaces of the base frame to reduce the noise of the impacting A-frame during folding.

It was also observed that the head of the bolts attaching the castors to the base frame catches on the side frames with a loud impact when the cage for is folded.

By experimentation it was found that the best method of remedying this was to fit a chamfered polycarbonate rubbing strip to the base plate which would allow the side frame to move smoothly and quietly over the bolt head. This solution, as shown in Figure 5.8 below, obviated the need to drill or to cut the steel cage or to countersink the castor bolt head.

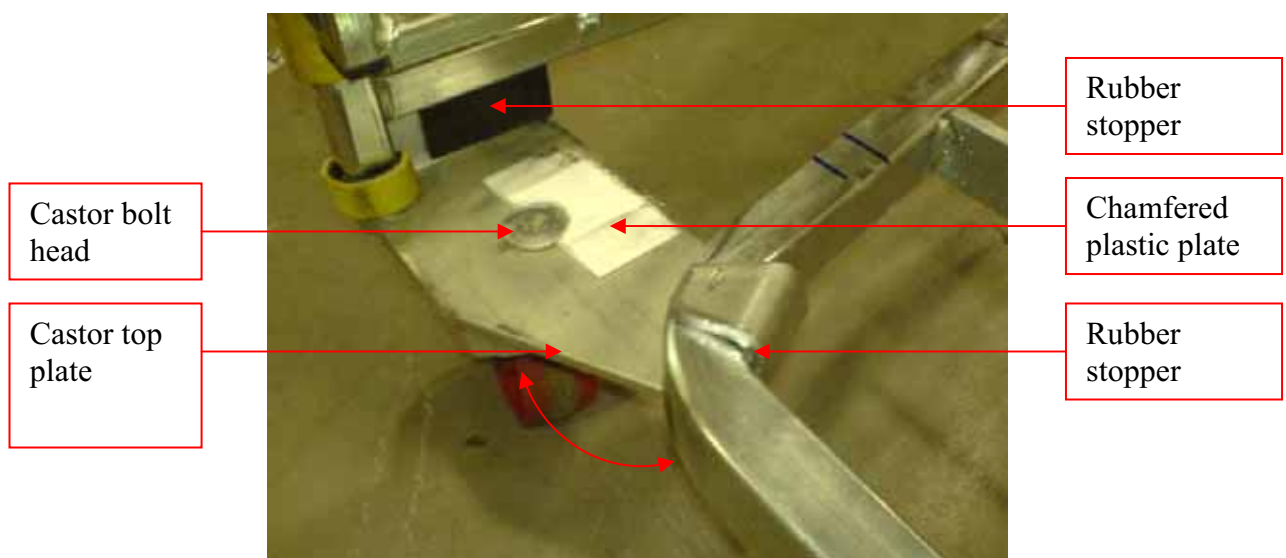


Figure 5.8. Photograph showing the castor head bolted on to the base-plate. The fitted polycarbonate chamfered plate and rubber stoppers are also illustrated.

The effectiveness of the acoustic add-on strips and stoppers and of the chamfered rubbing pieces were tested by dropping the cage floor 10 times onto the A frame and by repeatedly folding the cage and taking noise readings.

The noise reductions achieved are described in Table 5.3 and in Appendix III.

Table 5.3. Averages of the noise reductions achieved by modifications to the roll-cage

Modifications	Noise Levels dB(A)		
	Unmodified	Modified	Difference
Dropping of hinged floor onto "A-frame"	91.5	82.1	9.4
Closing / folding one side of roll cage	81.4	73.7	7.7

It can be seen that the damping modifications described in Table 5.3 and as illustrated in photographs 5.7 and 5.8, achieved significant noise reductions. The sound from the dropping of the hinged floor was reduced by 9.4 dB(A) and the impact noise arising folding of the sides of the cage over the castor knuckles was reduced by 7.7 dB(A).

Spectras of these events were prepared using the B&K acoustic software. The noise reductions across the frequency ranges achieved by the application of damping materials to the parts impacted by the opening and closing of the roll-cage can be clearly seen in Figure 5.9.

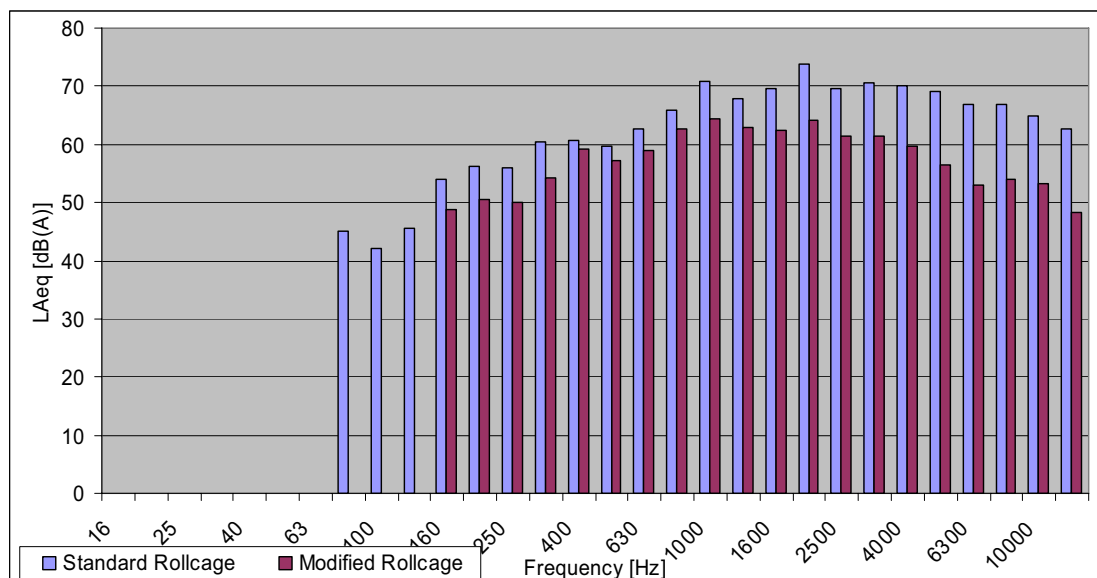


Figure 5.9. The spectra of a standard and a modified roll cage compared when the sides were folded together.

A significant noise reduction of 7.9 dB (from 80.6 dB to 72.7 dB) was achieved when the cage was repeatedly folded (x 10) as reported in Appendix III. As can be seen from Figure 5.9, the attenuation occurred across the whole frequency spectrum of the test, but was more pronounced at the higher frequencies above 4,000 Hz.

5.2.8. Collisions with walls

Roll-cages frequently collide with walls during deliveries to warehouses and to stores. To replicate this scenario a roll cage was pushed into a wall under controlled conditions, at consistent walking pace (3 km/h) before and after the application of damping modifications. This procedure was carried out for both loaded and empty roll cages. The loaded roll-cage carried an extra weight of 78 kg which was typical of a delivery consignment.

While consideration was given to controlling the impact speeds of the roll cages by erecting a ramp elevated at an appropriate angle to ensure a measured and replicable acceleration on collision with a barrier affixed to the bottom of the ramp. It was decided that the arrangement of employing a single operator to push the different cages at a consistent pace and of realising the cages at a measured distance of 1m from a concrete wall, would suffice as a pre-screening test which could be easily replicated. The logarithmic average noise level arising from ten repeated impacts was calculated. It was appreciated that using a ramp would generate an acceleration of the speed from the release of the cage (at 0 km/h) to the impact with the wall / barrier at 3km/h, rather than having a constant speed over the 1m measuring distance. It was also appreciated that the ramp apparatus could be designed to give a finely controlled impact speed with a barrier. Space and time constraints in the workshop however, would have made the erection of a large ramp apparatus problematical.

Rubber strips were glued along the prominent edges and corners of the cage frame most likely to make contact with walls and with other cages and obstacles. A modified empty cage was struck (10 times) against a concrete wall and the noise was measured at a distance of 3.5 m as described in Appendix III.4 and III.5. The measurements were compared with those taken by colliding an unmodified empty cage against the

wall. The experiment was repeated with a partly loaded modified and unmodified cage.

The application of the damping modifications achieved a very significant average noise reduction of 8.4 dB for the empty roll cage and 9.1 dB for the loaded roll cage. The average reductions are shown in Table 5.4 and are a summary of the noise measurements described in detail in Appendix III.

The load carried was 78 kg and with the weight of the rollcage included, it brought the total weight up to 108 kg. This would be the equivalent of loading the rollcage with 15 trays of baked beans, which is a typical weight for a loaded roll-cage in any supermarket (Musgraves, 2007).

Table 5.4. Noise reductions achieved by adding damping modifications when colliding empty and loaded rollcages against a wall.

Collision Tests	Noise Level (dB)		
	Unmodified	Modified	Reductions
Empty roll cage colliding with a wall	88.2	79.8	8.4
Loaded roll cage colliding with a wall	85.9	76.8	9.1

5.3. Evaluation of the full hush-kit applications

The development of the final hush-kit package followed from the results of the tests described and comprised the application of damping materials to all the resonating components and affected parts of the steel roll-cage.

The final hush-kit packages included the option of fitting rubber o-rings to the standard hard plastic wheels. Because of the additional cost involved in fitting o-rings, tests were carried out to see whether the fitting of o-rings was justified in terms of the incremental noise reductions achieved.

The modified empty and loaded cages were tested on the carousel and the results compared with the corresponding unmodified cages. The results are summarised in Table 5.5 and show the average noise recorded for each of the three tests carried out

as described on a modified loaded and empty cage fitted with o-ringed wheels and on a modified cage without o-ringed wheels. The carousel was set up, the speed was controlled at 3 km/h, the background noise was recorded and each trial was conducted for a period of 7 minutes.

Table 5.5. Noise reductions achieved by the application of the hush-kit to an empty and to a loaded cage.

Carousel Tests on Final Hush-Kit	Noise Levels in LA _{eq}		
	Standard	Modified	Reduction
Loaded modified cage with "o-ringed" wheels compared with a standard loaded cage	72.4 dB(A)	60.0 dB(A)	12.4 dB(A)
Empty modified cage with "o-ringed" wheels compared with a standard empty cage	73.7 dB(A)	59.2 dB(A)	14.5 dB(A)
Empty modified rollcage with "standard" wheels on the carousel compared with a standard empty rollcage	73.7 dB(A)	63.7 dB(A)	10.0 dB(A)

The application of the hush-kits gave very significant noise reductions as can be seen from Table 5.5. This was 12.4 dB in the case of the loaded cage and 14.5 dB in the case of the empty cage. The addition of the o-rings to the hush-kit accounted for a further reduction of 4.5 dB in the case of the empty cage.

The frequency spectra of the unmodified and modified roll-cages were also examined. This spectra is illustrated below in Figure 5.10. It can be seen that the noise attenuation was most pronounced at the higher frequencies above 7,000 Hz.

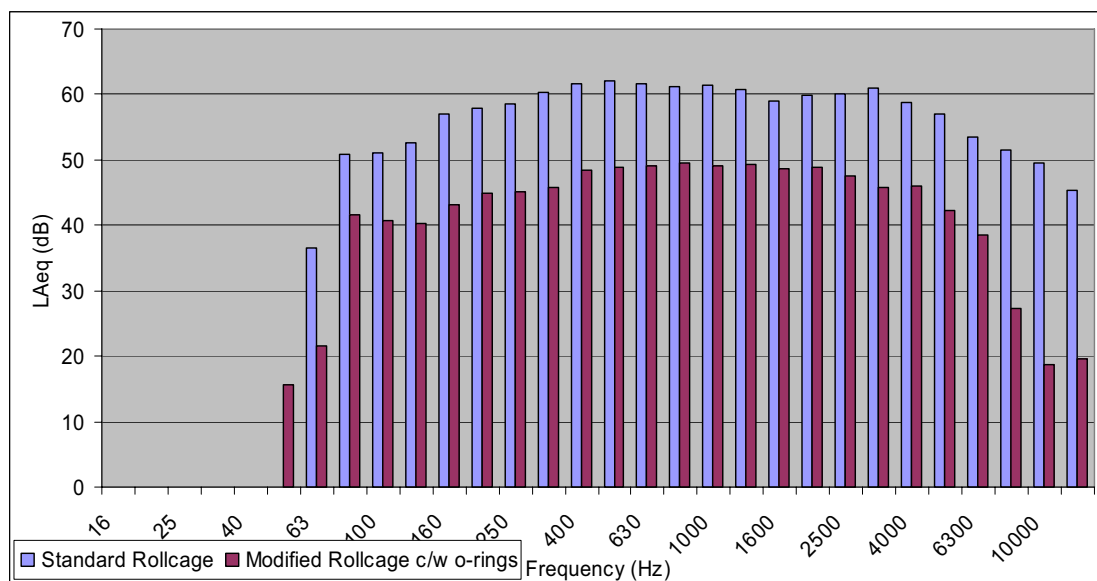


Figure 5.10. Noise reductions across the frequencies for a fully modified and "o-ringed" loaded cage compared with a standard loaded cage.

The experiment was repeated on an empty cage, one fitted with a full hush-kit containing the o-rings, and the other fitted with a kit omitting the o-rings. Figure 5.11 compares two versions of the hush-kit, one with o-rings and the other without, both applied to an empty roll-cage.

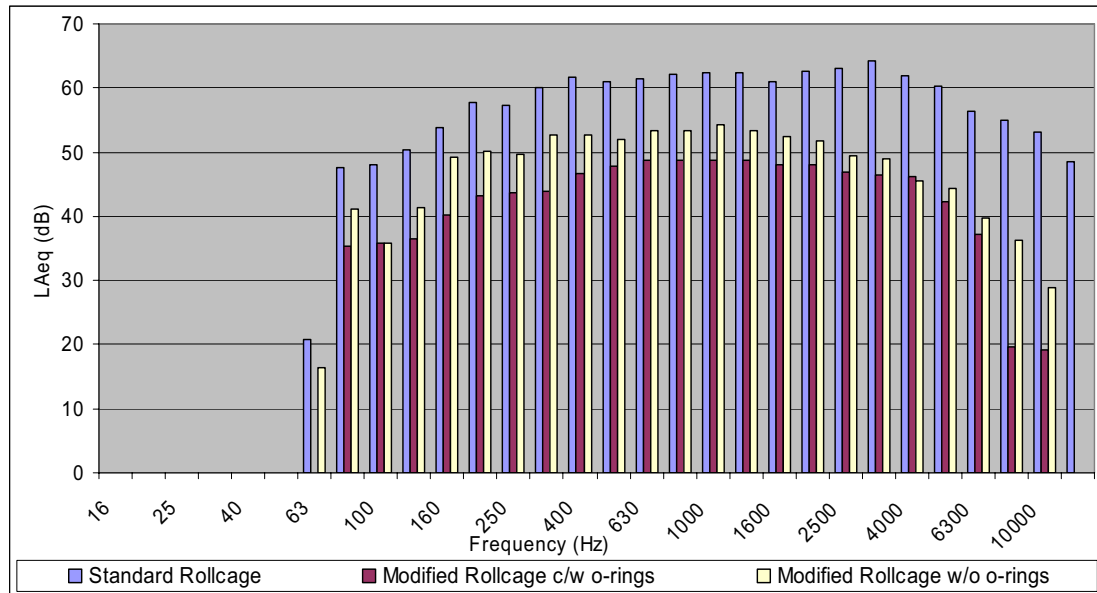


Figure 5.11. Spectras of an empty roll-cage, a modified roll-cage without o-rings fitted to the wheels, and a modified roll-cage without o-rings.

From Figure 5.11 it is clear that the hush-kit which includes the o-ringed wheels (maroon bars) is more effective than that without the o-rings (yellow bars) applied to the wheels. As noted already in relation to Figure 5.9, the attenuation was significantly greater at the higher frequencies.

The fitting of the hush kit achieved absolute values of below 66 dB for the handling of the roll-cages which is within the possible future noise limits that may be imposed by Dublin City Council (Dublin City Council 2007; European Commission 2002).

5.4. Preparation and application of the hush kit

In order to estimate the costs involved in the manufacture of the hush kit, a time and motion study was carried out. The components were fabricated from available raw materials such as hose pipes, sheets of rubber and rubber strips, and the kit was fitted using readily available workshop tools.

It was estimated that a full hush-kit, including the o-rings, could be supplied and fitted to a standard roll-cages at about 10 - 20 % of the original price of the cage (€ 180) and that the fitting could be done during regular servicing.

The tasks for retro-fitting the hush-kit include dismantling the cage; inserting the rubber washers on the castors; fastening and sticking tailored rubber strips and hose pieces onto the relevant metal surfaces; attaching the o-rings to the grooved wheels; fixing the chamfered polycarbonate sliding plates to the base plates; replacing metal clasps on the lattice work sides with plastic or rubber bands; applying damping strips to the identity panels and finally re-assembling the modified cage. These tasks are described in detail in Appendix III.6.

The rubber materials used for the experimental hush-kit comprised cast-off materials which were readily available in the DIT workshops. The aim was to develop a prototype which, if sufficiently promising could be developed further to ensure that the most appropriate materials and adhesives were used in order to ensure an optimum trade-off between acoustic performance, durability and costs. One aspect of the future research would be to determine whether it is feasible to use recyclable materials or whether it would be necessary to source specially formulated materials and adhesives.

5.5. Conclusion

Market research and interaction with the distributors as described in Chapter 2, strongly suggested that the application of a cheap retro-fit hush-kit for the conventional steel roll-cages would be an effective way for minimising the noise caused during night deliveries, particularly in the short to medium term. It would be unrealistic to expect businesses to replace their existing stocks of roll-cages with more expensive purpose-built “silent” cages while 200,000 conventional steel cages remained in circulation.

The methodology for developing the hush-kit involved the fabrication of a unique carousel test rig which could simulate the handling and passage of the roll-cages during deliveries, identify the resonating components and help to assess hush-kit

packages which could be easily retro-fitted. A suspended arm and tray was fitted to the carousel assembly to separately measure the effectiveness of applying rubber washers and o-rings to the roll-cage castors and wheels.

In addition to the carousel tests, the noise created when nesting the roll-cages and when colliding with an obstacle such as the wall of a warehouse was also recorded. Damping strips and rubber stoppers were applied to the effected parts to see how these peak sounds could best be attenuated.

The parameters for the assessment of a suitable hush-kit were deemed to be the noise attenuation achieved; ease of application; the use of readily available materials such as rubber stoppers and viscoelastic adhesive strips; durability and low cost.

The experiments led to the development of two versions of a roll-cage hush-kit, both of which included the fitting of tailored damping strips, of rubber stoppers and of chamfered polyamide lubricated rubbing plates to the impacted parts and to the resonating latticed sides of the roll-cage. The first hush-kit version did not have rubber o-rings fitted to the wheels while the second version had two o-rings fitted to each wheel in specially cut groves.

The application of the hush-kits showed significant noise reductions. The hush-kit (with the o-rings attached) when applied to an empty roll-cage showed significant average reductions of 12 dB(A) while the noise emanating from a loaded roll-cage was reduced by 14 dB(A). Because the o-rings accounted for 6 dB(A) of the overall reductions achieved, it was recommended to include these o-rings in the hush-kit.

The absolute noise value for the modified roll-cages was 60 dB(A), when rotated for seven minutes on the carousel. This is significantly lower than the possible 66 dB(A) limit which may be imposed by Dublin City Council in accord with the EC Directive. Significant noise reductions were also achieved when folding the retro-fitted cages for nesting inside the HGV trailer. The noise on dropping of the hinged floor onto the “A” frame was reduced by 9.4 dB(A) while the folding of the cage across the castor knuckles was reduced by 7.7 dB(A). However the absolute noise values for these events were in the region of 73 dB(A) and above which is above the limits likely to be

acceptable to Dublin City Council. From observations of a number of different deliveries it is reasonable to expect that a trained and adept operator could carry out the nesting of the roll-cages much more quietly within a peak limit of 66.6dB(A). Incentives could be awarded by the logistics service providers to ensure that a satisfactory level of acoustic performance was maintained during night deliveries. DIT has offered to develop a training manual for logistics operatives based on this research.

The hush-kit reduced the noise caused by collisions with a wall, by 8.9 dB(A) for an empty cage and by 9.1 dB(A) for a loaded cage. While the absolute values were again high at 75 dB(A), in practice, these impacts could be completely avoided or greatly mitigated by a trained operator.

It was found that the noise attenuations achieved by the fitting of the hush-kits occurred right across the frequency ranges from 500 Hz to 10,000 Hz and were very pronounced above 7,000 Hz. As reported in chapter 3 and shown in Figure 5.9, signature frequencies and pure tones at 1,000 Hz and above were characteristic of the handling of empty roll-cages and the application of the hush-kit was most effective at these high frequencies.

A hush-kit can be manufactured cheaply from rubber off-cuts and from commercially available viscoelastic strips and adhesives and can be easily retro-fitted. A time and motion study indicated that the total cost of preparing and applying a hush-kit including o-rings would amount to € 26 and it was reasonable to assume that costs could be significantly reduced by series production. The additional cost to a distributor or retailer of “quietening” his roll-cages would add from 10 % to 20 % to his original price and this operation could be included as a part of the regular servicing.

Further development work is recommended to ensure that the most appropriate rubber materials and adhesives are selected so as to optimise the trade-offs between acoustic performance, durability and costs of a commercially attractive product.

CHAPTER 6: OVERVIEW, CONCLUSIONS AND RECOMMENDATIONS

6.0. Introduction

The project set out to prove the hypothesis that –

Acoustic materials are available or can be developed and applied to Heavy Goods Vehicles and ancillaries, which effectively and economically abate the noise caused by night deliveries

The background and justification for the research are described in chapter 1. The methodology by which this hypothesis was proven and the research results obtained are described in chapters 2 to 5.

Public concern with noise pollution has moved up the European political agenda. In the interests of ensuring a satisfactory quality of life for residents many municipal authorities have taken steps to mitigate the nuisance caused. As reported in chapter 1, the damaging effects of sleep deprivation caused by traffic and by aircraft noise, are supported by a significant body of medical research (EC-CALM 2005, WHO 2001). In Dublin the City Council through its noise mapping activities and action plans in response to the EC noise directive (EC-ENDS, 2002) and DIT through the Innovation Partnership project “*Low Noise Solutions for Night Deliveries*”, has helped to make the city a significant voice in this topical European debate (Byrne, Finlay and Grimes, 2007).

The Innovation Partnership built on earlier research conducted by the author that has created new insights into the patterns and rhythms of deliveries to shops in the city centre. The parameters that had relevance for noise disturbance were the time of day at which deliveries occur; the dwell times of trucks while delivering at the kerb-sides; the categories of goods delivered and the types of vehicles used. The trend to urban night deliveries were found to be driven by powerful factors; 24/7 shopping; the desire by distributors to avoid congestion peaks; by the advent of just in time deliveries and

e-logistics and by the need for retailers to free up customer access to their premises during the day (O'Mahony, Finlay and Finnegan, 2004). A survey of 2,500 deliveries to city centre shops during a typical week in 2005 showed that 24 % of trips were made before the 7am congestion peak (NITL, 2007). This trend is likely to have accelerated following the introduction in February 2007 by Dublin City Council of the HGV Strategy which restricts access by five axle trucks to the centre during the day.

The need to conduct night deliveries in a sustainable way acceptable to residents is expected to create a demand for low noise products and solutions. The market research as reported in chapter 1 makes a convincing business case for the project. This suggests that the demand for low noise HGV trailer units and ancillaries will be significant when related to the numbers of newly registered heavier HGVs (over 16 tonnes gross vehicle weight) which are increasingly employed for the deliveries of foodstuffs. When it is considered that 3,200 of the bigger HGVs enter the Irish market every year and that each trailer unit may contain up to 48 roll-cages, a potentially large market may develop if new HGVs and a proportion of the existing fleet require acoustic modifications in order to enjoy access to noise sensitive areas.

The Dutch "PEAK" programme has created a very relevant body of best practice experience on which this research has built. The Dutch government have since 1998, set stringent noise limits for night operations in their major towns and have successfully encouraged the development of a new range of acoustic products. A combination of regulations for night deliveries together with government subsidies has stimulated sales of "quiet" products to the value of € 60 million in the period 2004-2008 (Senter Novem-PEAK, 2002).

Interaction with the PEAK programme was arranged through the Dutch agency Senter Novem and also with other relevant EC research networks, namely "BESTUFS", "CALM" and "SILENCE" (BESTUFS 2005; CALM 2006; SILENCE 2005). It became evident from a review of these programmes however that no "one size fits all" solution could be found and in the case of Dublin, that there was scope to develop new solutions for selected niche applications which would have regard for the unique topography and relatively cold climate of the coastal city and which would match the capabilities of Irish based suppliers.

An examination of the events that gave rise to the peak noises during deliveries suggested that the focus of the research could usefully be directed at (a) selecting acoustic materials for application to HGV trailer units and tail-lifts and (b) developing “hush-kits” that could be retro-fitted to roll-cages.

6.1. Literature review and research methodology

The research methodology, as described in chapter 2, comprised eight discreet tasks –

- 1) a review of national and international regulations and norms governing noise disturbance
- 2) a social and commercial justification for the research
- 3) field trials to identify the peak disturbances caused during kerb-side deliveries
- 4) the selection and development of suitable materials for noise abatement
- 5) the acoustic pre-screening of coatings in the laboratory
- 6) a repeat of the laboratory tests on board a “concept” HGV
- 7) the evaluation of modified roll-cages fitted with “hush-kits”
- 8) conclusions and recommendations for further investigation

The research methodology and the sequence in which the tasks were carried out were found to be practical and gave results that confirmed the proposed hypothesis. The methodology was based on a review of the literature relating to vibration and noise control and to the procedures used by the authorities in Ireland and internationally for measuring noise disturbance.

The analysis of the results of the field trials of night deliveries in the city centre (Task 3) was the basis for deciding which components and products would need attenuation having regard to the levels and characteristics of the peak noises caused and to the feasibility of finding realistic solutions.

The project sought to build on the research reported by the Dutch PEAK programme by seeking to attenuate the peak sounds at the characteristic frequencies at which they

occurred. The development and analysis of frequency spectra for the peak events and the matching of these particular peak frequencies with suitable acoustic materials, was seen as an advance on the work carried out to date.

The initial field trials involved measuring absolute values for the peak sounds caused by deliveries on the streets (as reported in chapter 3). The subsequent trials in the laboratory and on board the HGV “concept vehicle” assessed the effectiveness of applying different acoustic materials to a variety of substrates. Relative values rather than absolute values were deemed to be sufficient for making comparisons. All the sound measurements were made by adapting BS 4142 procedures. The development of special test rigs comprising a portable pendulum, a falling weight rig and a hydraulically driven carousel assembly were unique to the project. The laboratory tests were devised to ensure that the test conditions could be easily repeatable, changing only the material or noise abatement method.

The procedures commonly used by the local authorities and the courts for dealing with noise complaints were examined and were found to be based on BS 4142 (EPA Guidelines, 2003). When complaints are made, the additional noise or “exceedences” (greater than 6 dB(A)) caused by disturbances are compared with the background noise and these values are taken into account by the courts. Rather than seeking compliance with absolute noise limits, which is the practice in the Netherlands and in Germany, the Irish courts are more concerned with adjudicating on the added disturbances caused by particular events.

The Bruel and Kjaer sound meters were programmed to record the key parameters specified in BS 4142 and “Evaluator” software was used to analyse the data and to develop spectra for the peak events. Graphic data was recorded by using night vision cameras and this enabled the sources of the peak events to be easily identified. It was found that the peak events could be characterised by “signature frequencies” as shown on the spectra and that for example, the manipulation of roll-cages could be easily distinguished from the movements of the hydraulic tail-lift or the running of the HGV refrigeration system.

When comparing the peak measurements taken in Dublin with measurements recorded in the Netherlands by TNO, the former should be adjusted by adding 6.6 dB(A) to the

TNO readings for similar events so as to correct for the closer positioning of the sound meter during the Dublin field trials. If the noise limits which apply to the Dutch cities were to be adopted by Dublin City Council, the limits for night delivery events would be set at LA_{eq} 66.6 dB(A) measured continually at 1 second intervals over the duration of the delivery operation. The challenge for businesses making deliveries in Dublin is therefore to attenuate the peak sounds such as those arising from the handling of the roll-cages, to within limits approaching LA_{eq} 66.6 dB(A).

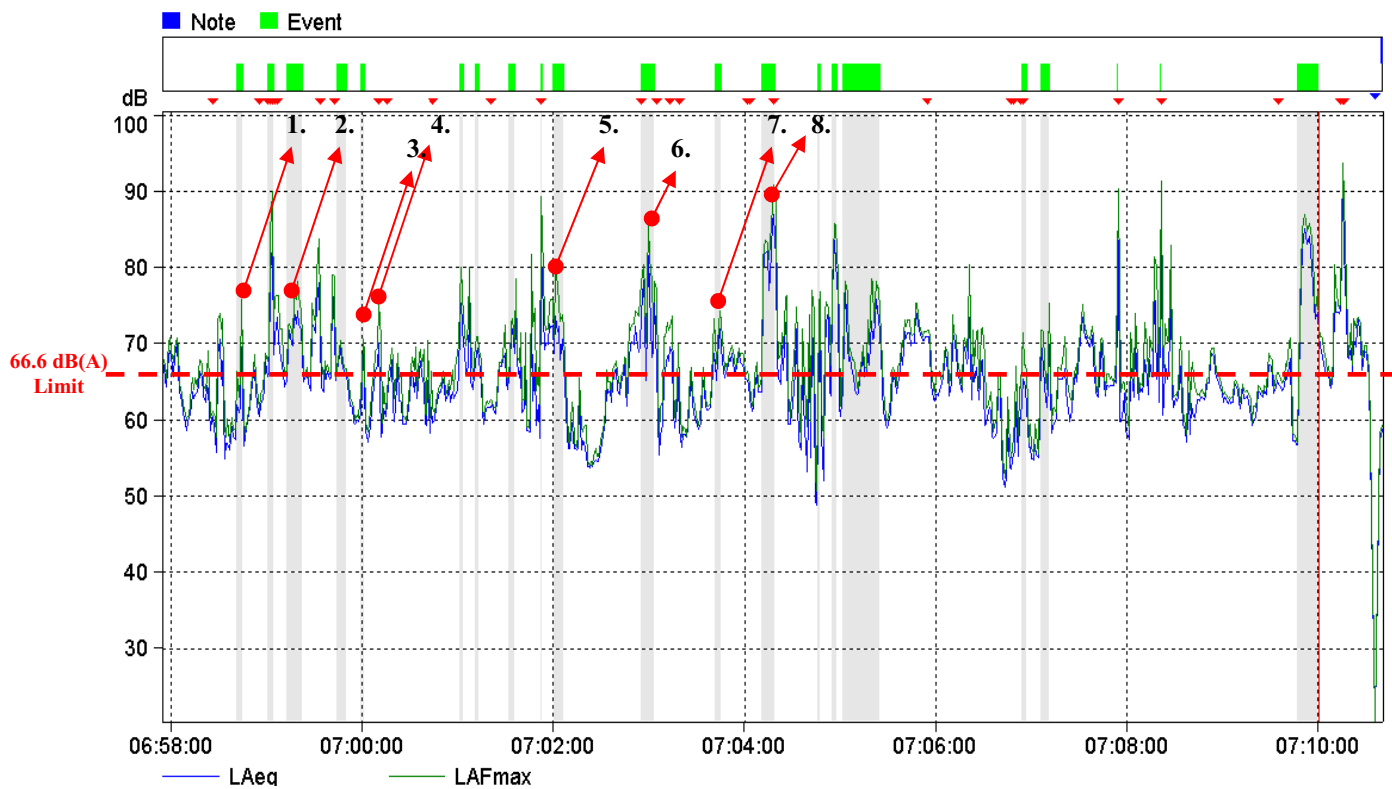
6.2. The monitoring and analysis of kerb-side deliveries

Kerb-side deliveries to shops, as reported in chapter 3, were found to make a significant difference to the background early morning noise on the city streets. This was the case whether deliveries took place in a ‘low noise sensitive area’ or on a busy street with lots of by-pass traffic. The shops were selected with a view to giving a representative sample of different street-scapes, from narrow “canyon” streets where noise is reverberated, to wide tree-lined streets. The delivery operations were found to generate peak sound levels which added significant noise values ranging from 14.7 dB(A) to 20.6 dB(A) to the background sound levels.

The events that caused most of the peak sounds related to the handling of the roll-cages were their passage along the floor of the HGV trailer, when transiting the tail-lift platform, when crossing the pavements to the shops and when stacking the returned empty cages inside the trailer unit.

The manipulation of the roll-cages within the trailer body at store C produced typical values of LA_{eq} of 72.7 dB(A) and an LAF_{max} of 79.1 dB(A). The return of the empties to the truck and onto the tail-lift generated an LA_{eq} of 71.7 dB(A) and an LAF_{max} of 83.2 dB(A). The spectra for the empty roll-cages were characterised by a concentration of “signature” frequencies in the region of 1,000 Hz to 2,000 Hz while the partly loaded cages showed a spread across a broader range of frequencies. The pure tones or tonal quality that causes most annoyance were identified on the spectra by the increases of 3 dB or more at the peak events. For example a pure tone at 1,000 Hz characterised the peak sounds caused by the handling of the empty cages.

The peak events caused by the handling of the roll-cages at store D are shown in Figure 6.1 (with reference to chapter 3) and the peaks are also shown in relation to a possible city centre noise limit of 66.6 dB(A) for night deliveries. It can be seen that the handling of the roll-cages gives rise to peaks in excess of 76 dB(A) LA_{eq} which is significantly greater than the targeted limit of an LA_{eq} of 66.6 dB(A) measured for intervals of 1 second.



	Name	Start time	End time	Duration	LAeq [dB]	LAF90 [dB]	LAFmax [dB]	Remarks
	Total	22/06/2006 06:57:55	22/06/2006 07:10:41	0:12:46	71.2	57.6	93.8	
	Unmarked	22/06/2006 06:57:55	22/06/2006 07:10:40	0:10:38	68.1	57.2	93.8	
	(All) Note	22/06/2006 07:10:40	22/06/2006 07:10:41	0:00:01	58.8	58.4	59.4	
	(All) Event	22/06/2006 06:58:41	22/06/2006 07:10:01	0:02:07	76.8	63.1	91.2	
	Note	22/06/2006 07:10:40	22/06/2006 07:10:41	0:00:01	58.8	58.4	59.4	Conditions: dry, 10 degrees C, high wind speeds
1.	Event	22/06/2006 06:58:41	22/06/2006 06:58:48	0:00:05	64.5	56.1	75.8	Full roll cages moving onto tail lift from truck body
	Event	22/06/2006 06:59:01	22/06/2006 06:59:05	0:00:04	78.7	63.9	89.9	Lugs folded down with full cages moving along pavement
2.	Event	22/06/2006 06:59:13	22/06/2006 06:59:23	0:00:10	71.9	68.6	78.2	Full roll cage moving along pavement
	Event	22/06/2006 06:59:44	22/06/2006 06:59:51	0:00:07	67.4	65.8	70.4	Tail lift moving upwards with no roll cages
3.	Event	22/06/2006 06:59:59	22/06/2006 07:00:02	0:00:03	65.8	60.2	70.6	Full roll cages moving from trailer body onto tail lift
4.	Event	22/06/2006 07:01:01	22/06/2006 07:01:04	0:00:03	73.0	69.0	80.1	Full roll cages moving from tail lift onto pavement
	Event	22/06/2006 07:01:11	22/06/2006 07:01:14	0:00:03	68.7	67.0	70.9	Full roll cage moving along pavement to store & passing traffic
	Event	22/06/2006 07:01:32	22/06/2006 07:01:37	0:00:05	71.2	66.7	78.5	Passing bus
	Event	22/06/2006 07:01:52	22/06/2006 07:01:54	0:00:02	79.7	55.0	89.2	Door of 'pay&display' box closing
5.	Event	22/06/2006 07:02:00	22/06/2006 07:02:07	0:00:07	70.8	66.1	79.9	Full roll cages moving along pavement to store
6.	Event	22/06/2006 07:02:55	22/06/2006 07:03:04	0:00:09	76.1	64.8	86.0	Empty roll cages moving from footpath onto tail lift
7.	Event	22/06/2006 07:03:42	22/06/2006 07:03:46	0:00:04	69.9	64.7	74.4	Full roll cage moving along pavement to store
8.	Event	22/06/2006 07:04:11	22/06/2006 07:04:20	0:00:09	82.7	75.7	90.9	Empty roll cages moving along pavement to truck
	Event	22/06/2006 07:04:46	22/06/2006 07:04:48	0:00:02	71.1	49.5	76.8	Securing of empty roll cages on tail lift
	Event	22/06/2006 07:04:55	22/06/2006 07:04:59	0:00:04	80.3	75.2	85.8	Securing of empty roll cages on tail lift
	Event	22/06/2006 07:05:02	22/06/2006 07:05:28	0:00:24	70.7	64.0	78.5	Tail lift moving upwards with empty roll cages
	Event	22/06/2006 07:06:54	22/06/2006 07:06:58	0:00:04	64.3	58.4	71.3	Noise from inside the trailer body (cages moving around)
	Event	22/06/2006 07:07:06	22/06/2006 07:07:12	0:00:06	67.4	60.4	75.3	Noise from inside the trailer body (cages moving around)
	Event	22/06/2006 07:07:54	22/06/2006 07:07:55	0:00:01	83.6	60.2	90.2	Folding of tail lift lugs
	Event	22/06/2006 07:08:21	22/06/2006 07:08:22	0:00:01	85.8	70.0	91.2	Folding of tail lift lugs
	Event	22/06/2006 07:09:47	22/06/2006 07:10:01	0:00:14	80.6	66.2	86.9	Truck driven away

Figure 6.1. Specific noise at store D and data log, LA_{eq} measured at 1second intervals. The peaks numbered 1 to 8 relate to the remarks in the accompanying datalog.

6.3. The selection of a damping material for the HGV trailer and tail-lift platform

The question of which category of acoustic material to select and apply was considered. The categories comprised (1) absorption (2) transmission loss and (3) damping materials as described in chapter 4. It was decided to focus on damping solutions because the peak sounds were caused by impacts with resonating metal surfaces which emitted relatively high frequency sounds.

Following an examination of the construction of an HGV and having observed the location of the resonating surfaces which suffer frequent impacts, it was decided to apply damping in the form of a coating to the aluminium floor and kick-walls of the trailer and to the mild steel tail-lift platform. The restricted dimensions and spaces

available for sound attenuation in a standard HGV trailer would not permit the installation of bulky absorption or barrier materials and the much thinner damping materials and coatings would be easier to retro-fit and were likely to give a more durable solution.

The acoustic pre-screening in the laboratory of a special coating developed by CREST-DIT was completed before application on a bigger scale to an HGV trailer unit and tail-lift. Tests were designed to simulate the events that occur during deliveries and special rigs comprising a falling weight rig and a pendulum apparatus were fabricated, as described in chapter 4. The boundary conditions for the laboratory tests were set to ensure repeatability. For example the torques applied to securing the panels under test on the pendulum apparatus by means of clamps were measured.

Following completion of the impact testing in the laboratory, the coating was tested on board a “concept” HGV trailer unit using the portable falling weight and pendulum test rigs.

The methodology used for evaluating the acoustic performance of the coating on different HGV trailer body substrates (aluminium, mild-steel and GRP) and for measuring the coating against selected proprietary materials, enabled realistic comparisons to be made.

Consideration was given to employing a vibrating bar or “Oberst” bar to measure the damping performance of the coating on small sample panels of the substrates but this was discounted because the aluminium and mild steel panels were relatively thick and of dense cross-section (3mm) and would not be comparable with the vibrating behaviour of thin diaphragms under tension. The portable test rigs developed for the project were deemed to give acceptable comparative data.

The coating showed very promising noise reductions possibilities in the laboratory and the test results reported in chapter 4 are summarised below in Table 6.1.

Table 6.1. Summary of noise reductions achieved in the laboratory by the application of an acoustic coating and damping strips to GRP, mild steel and aluminium panels using the falling weight test

Substrate	Uncoated Log. Average dBA (LAF_{max})	Coated Log. Average dBA (LAF_{max})	Reductions in dB, coated panels compared with uncoated
Aluminium, chequered side	102.9	88.1	14.8
Aluminium, plain side, plus “Ygro”	104.3	88.8	15.5
Mild Steel, chequered side only	100.3	85.6	14.7
Mild steel, plain side, plus “Ygro”	99.6	90.3	9.3
GRP	98.3	91.2	7.1

It can be seen that the falling weight tests conducted in the laboratory showed very significant reductions of 14.8 dB(A) for the coated aluminium and 14.7 dB(A) for the coated mild steel panel and compared favourably with the application of the proprietary adhesive damping strips.

It is interesting to compare the results reported in the laboratory for the falling weight test with the corresponding results obtained on board an HGV trailer at the distribution depot test site. The high attenuations achieved in the laboratory were not experienced on board the HGV trailer but they were nevertheless still significant. Reductions of 6.0 dB(A) were recorded for the coated aluminium panel and 9.0 dB(A) for the coated mild steel.

In the case of the falling weight tests the attenuation patterns across the frequency ranges recorded in the laboratory can be compared with the patterns recorded on board the HGV trailer unit at the test site. The superimposed spectra for the laboratory tests and for the repeat of these tests on board the HGV trailer unit are illustrated below in Figure 6.2.

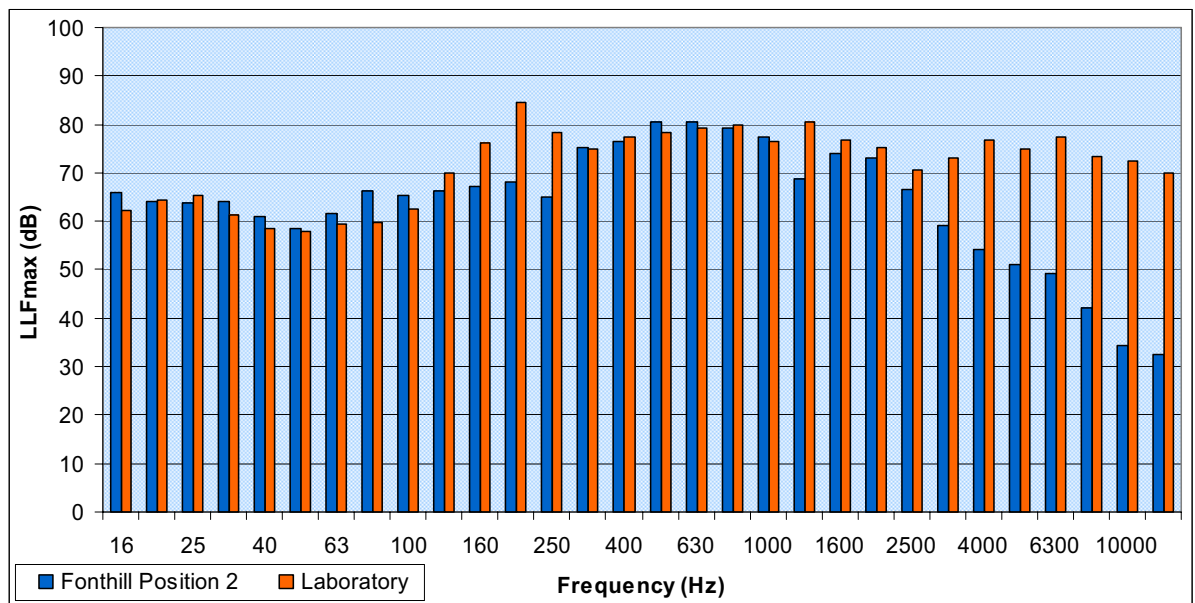


Figure 6.2. Comparison of falling weight spectra for a coated aluminium panel tested in the laboratory and with a spectra for position 2 as tested at test site.

It can be seen from Figure 6.2 and also in chapter 4 Figure 4.29, that very significant attenuation was recorded at the test site at frequencies above 1,600 Hz, which was not the case in the laboratory. This may be explained by the different boundary conditions obtaining in the laboratory compared with the inside of the HGV trailer unit in the open field. The relatively thick GRP walls of the trailer evidently had transmission loss effects on the higher frequency sounds. It should be noted that the panels under test were not mechanically secured to either the floor of the laboratory or to the floor of the HGV trailer.

It is possible that the higher frequencies emanating from position 2 inside the trailer (as illustrated in chapter 4, Figure 4.25) may have been absorbed by the thick GRP side walls whereas in the laboratory these frequencies would have been reflected by the dense concrete walls within a confined space. The GRP walls may therefore have given some additional transmission loss effects at the higher frequencies. For example if one compares the expected transmission losses through a 6.35mm ($\frac{1}{4}$ ") thick plywood wall as being roughly similar to the transmissions through a GRP trailer wall, an attenuation of 15 dB at 250 Hz and 25 dB at 8,000 Hz might be expected (Bell and Bell, 1994, p.219).

The clear peak at 250 Hz which was evident in the laboratory was not evident at the test site. As reported in chapter 4, this particular peak was characteristic of all the aluminium tests conducted in the laboratory.

Similar comparisons can be made between the spectra for the falling weight tests for the coated mild steel panel conducted in the laboratory and for the similar tests conducted at the test site. The superimposed spectra are illustrated in Figure 6.3 (this is also shown in chapter 4, Figure 4.30).

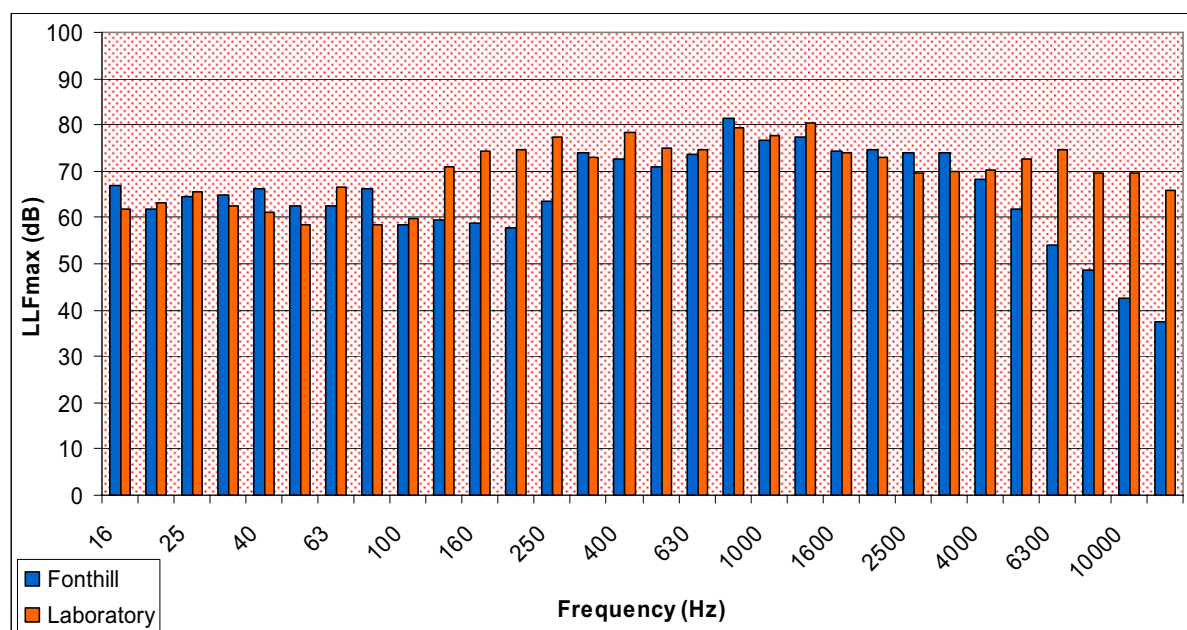


Figure 6.3. Comparison of the spectra for a mild steel coated panel tested with the falling weight in the laboratory with placement on the HGV tail lift platform at the test site.

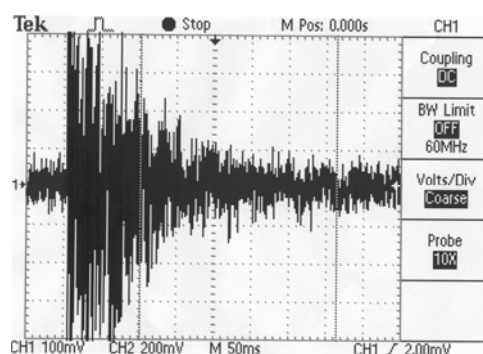
It can be seen from Figure 6.3 that the attenuation recorded in the test site was significant between 100 Hz and 250 Hz and greatest at the higher frequencies above 4000 Hz, unlike the laboratory tests where the higher frequencies were little affected. The greater attenuation at the higher frequencies recorded in the test site may be explained by reverberation occurring in the confined spaces of the laboratory building when none was likely in the open logistics yard at the test site, because the higher frequency sounds could easily dissipate in the open spaces. It is more likely however that the different boundary conditions gave rise to natural frequencies occurring at different places in the spectrum.

A comparison can also be made between the spectra for the coated aluminium panel taken at the test site as shown in Figure 6.2, where attenuation occurred at 1,600 Hz, and the mild steel panel where attenuation occurred at the higher frequencies of 4,000 Hz and above, as illustrated in Figure 6.3. This may be explained by the different constraints and environment obtaining in the laboratory compared with onboard the HGV trailer unit. It should be noted however that the clamping forces applied to the portable pendulum apparatus for securing the panels were similar on board the HGV to those in the laboratory.

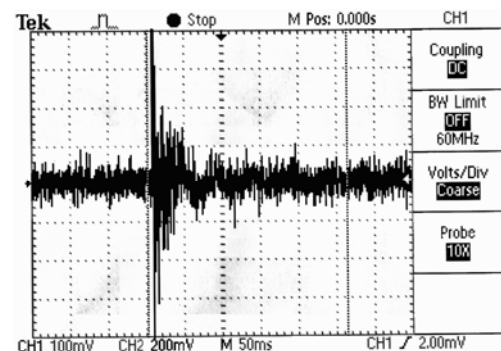
The tests on both the aluminium and mild steel panels at the test site showed noticeable reductions in the higher frequencies above 2500 Hz and because the test site is closer to the intended environment of deliveries to shops where high frequency sounds caused by the roll-cages are very much in evidence, the attenuation pattern achieved by the application of the acoustic coating is encouraging.

6.3.1. Reverberation effects on coated and uncoated aluminium and mild steel panels compared

The damping effects of the coating were confirmed by comparing the decay characteristics of impacted uncoated and coated aluminium and mild steel panels. Graphs comparing the decay times for uncoated and coated panels on being struck by the pendulum weight are represented in Figures 6.4 and 6.5.

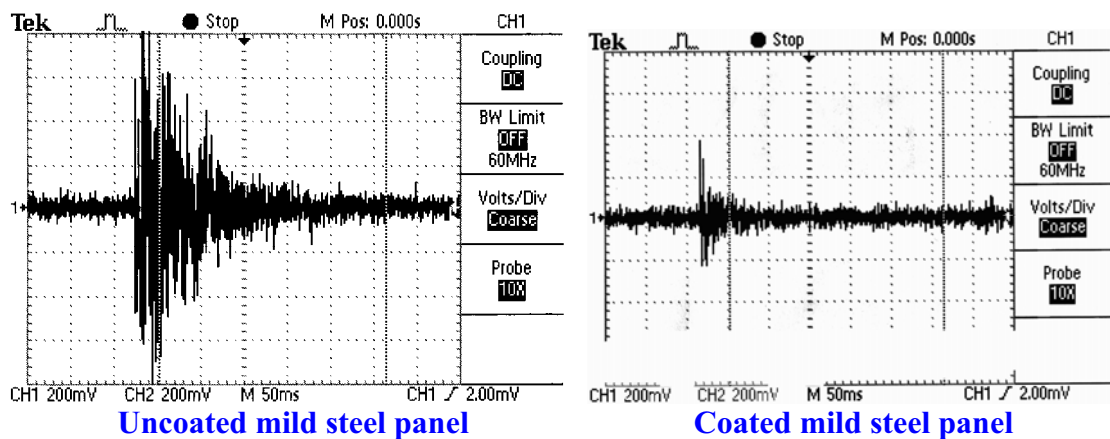


Uncoated aluminium panel



Coated aluminium panel

Figures 6.4. Graphs comparing the decay times for the impacts of the pendulum on coated and uncoated aluminium panels.



Figures 6.5. Graphs comparing the decay times for the impacts of the pendulum on coated and uncoated mild steel panels.

The decay times for the impacted aluminium and mild steel panels were reduced by a factor of four when measured on an oscilloscope. The reverberation time was reduced from an average of 200 milliseconds to 50 milliseconds for the coated aluminium panels, while a reduction of 100 milliseconds to 25 milliseconds was recorded for the coated mild steel panel. These decay time results confirmed the damping effectiveness of the coating as shown by the sound meter tests reported in chapter 4.

The application of a damping material in the form of an acoustic coating to the substrates used on the floors and tail-lift platforms of an HGV trailer were promising. While the noise attenuation recorded under the controlled laboratory conditions was much greater than that recorded out in the open on board an HGV trailer unit, the latter results were still impressive and repeatable and showed a reduction of 5.4 dB(A) in the case of the coated aluminium panel and 9.0 dB(A) in the case of the coated mild steel.

While the coating was effective in damping the vibrating aluminium and mild steel panels, it was not found suitable or effective for application to GRP. It should be noted that the preliminary laboratory tests reported in chapter 4.4.1 indicated that the new coating also performed better acoustically than did a Dutch proprietary liner coating which claimed to have both protective and acoustic properties. All of these results confirm the potential of the new coating as an effective acoustic application.

Any recommendation to apply the coating to cover the whole floor area of an HGV should however, await the development of a more robust formulation which could withstand up to two years in fleet service because the tests on the carousel indicated a life of not more than one year. A longer lasting coating would require the application of a thicker or harder polyester top coat and it remains to be seen whether a harder and stronger top coat would diminish the damping properties of the overall three layer formulation which comprises a primer, a viscoelastic middle layer and a top layer.

In fleet operation the application of the acoustic coating to the HGV trailer floor and tail-lift could be expected to reduce peak noise levels by 5 dB(A) or more. For example a typical peak of LA_{eq} 71 dB(A) caused by the handling of the roll-cages would be sufficiently reduced to conform with the proposed limit of 66 dB(A) for night deliveries to be considered by the City Council. This degree of attenuation would not however be sufficient to achieve the proposed limit of 66 dB(A) for the higher peak noises recorded during the initial field trials. The development therefore of a special “hush-kit” for the roll-cages to mitigate the high frequency rattling noises at source, was seen as a necessary additional requirement to complement the application of the coating and to help achieve the proposed target peak limit of 66 dB(A).

6.4. Damping to the roll-cages by the application of a “hush-kit”

The field trials indicated that the handling and rattling of the roll-cages contributed greatly to the peak noise events and hence the challenge was to develop an inexpensive way to attenuate these noises by means of a hush-kit that could be easily retro-fitted.

In order to attenuate the frequency sounds which were found to be characteristic of the manipulation of roll-cages, as reported in chapter 3, it was decided to apply damping materials in the form of viscoelastic strips and rubber bands and stoppers to the affected parts of the roll-cage. It was realised that the application of an acoustic coating to the HGV trailer floor would not be sufficient to mitigate the peak sounds

caused by the handling of the roll-cages and that the attenuation of the peak sounds at source by the application of a hush-kit would be necessary.

Market research (chapter 2) suggested that the development and application of a cheap retro-fit hush-kit for the conventional steel roll-cages could be an acceptable solution in the short to medium term. It would be unrealistic to expect businesses to replace their existing stocks of roll-cages with new and more expensive purpose-built “silent” cages while 200,000 conventional steel cages remained in circulation.

The development of the hush-kit involved the fabrication of a special carousel test rig designed to simulate the handling of the roll-cages during deliveries, to identify the resonating components and to assess different hush-kit package options. A suspended arm and tray was added to the carousel assembly to measure the effectiveness of applying rubber washers and o-rings to the roll-cage castors and wheels (as detailed in chapter 5).

The components of the roll-cage which vibrate while the cage is in motion were identified and marked, as illustrated in Figure 6.6 (these are also shown in chapter 5, Figure 5.1).

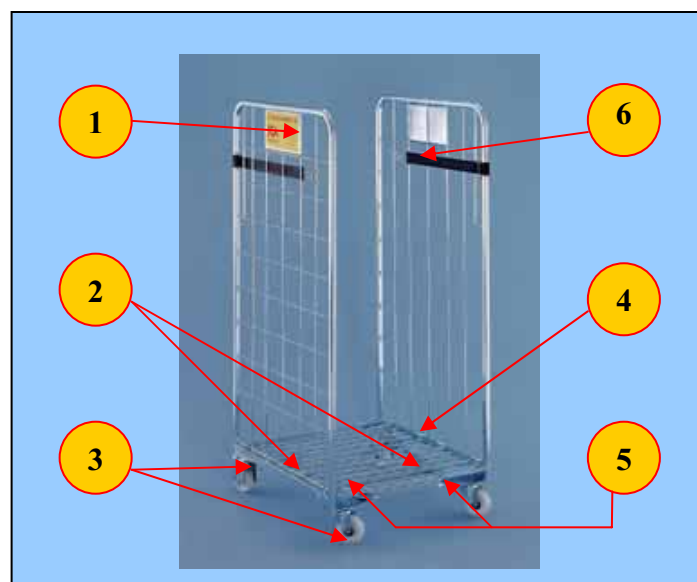


Figure 6.6. Photograph of vibrating roll-cage parts.

The noise created when nesting the roll-cages and when they hit walls and other obstacles was also simulated by repeatedly colliding empty and loaded cages against a concrete wall. Damping strips and rubber stoppers were applied to the effected parts to

see how these peak sounds might best be attenuated. The parts of the roll-cage affected during nesting and when colliding together are shown in Figure 6.7 (these are also shown in chapter 5, Figure 5.2). These particular tests are described in more detail in chapter 5.

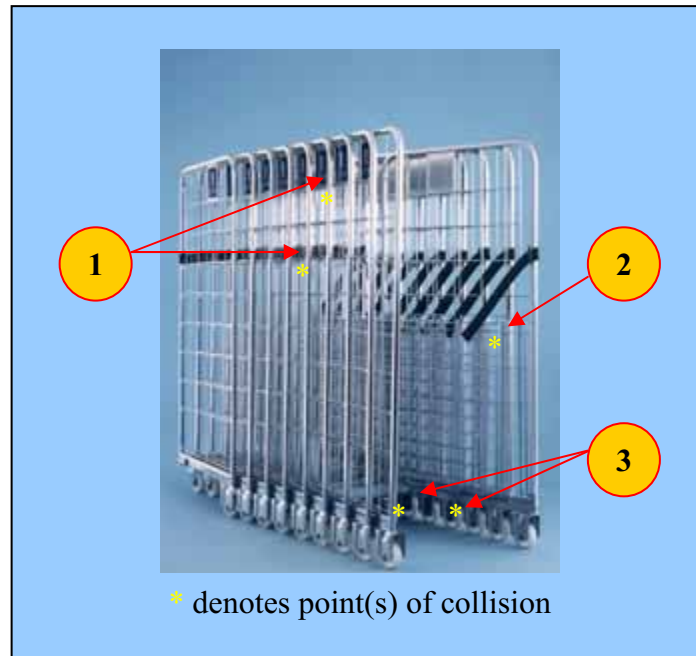


Figure 6.7. Photograph of components affected by nesting

The requirements for a suitable hush-kit were specified as comprising: significant noise attenuation; ease of application; the use of readily available materials such as rubber pieces and viscoelastic adhesive strips; durability and low cost.

The carousel experiments as reported in chapter 5 and the related experiments which simulated nesting and collisions, led to the development of a hush-kit which comprised; (a) the fitting of tailored damping strips to the resonating surfaces of the cages, (b) of rubber stoppers to the impacted parts, (c) of rubber bands to the metal side lattices, (d) of chamfered polyamide lubricated rubbing plates to the folding parts. The components of the hush-kit are illustrated in chapter 5 and related appendices. Two versions of the hush-kit were developed and tested; the first version did not have rubber o-rings fitted to the wheels while the second version had two rubber o-rings inserted into specially cut groves.

The results of the noise recorded for three different tests are described in Table 6.2. These tests were devised to give easily repeatable and comparable results. The effectiveness of the hush-kit when fitted to both an empty and to a loaded cage was

assessed by running the cages on the carousel for seven minutes, measuring the sound and comparing these with the noise from an unmodified cage.

Table 6.2. Noise reductions achieved by the application of the hush-kit to an empty and to a loaded cage.

Carousel tests on final hush-Kit	Noise Levels in LA _{eq}		
	Standard	Modified	Reduction
Loaded modified cage with "o-ringed" wheels compared with a standard loaded cage	72.4 dB(A)	60.0 dB(A)	12.4 dB(A)
Empty modified cage with "o-ringed" wheels compared with a standard empty cage	73.7 dB(A)	59.2 dB(A)	14.5 dB(A)
Empty modified roll-cage with "standard" wheels on the carousel compared with a standard empty roll-cage	73.7 dB(A)	63.7 dB(A)	10.0 dB(A)

As can be seen from Table 6.2, the application of the hush-kits gave very significant noise reductions. This was 12.4 dB in the case of the loaded cage and 14.5 dB in the case of the empty cage. The addition of the o-rings to the hush-kit accounted for a reduction of 4.5 dB in the case of the empty roll-cage and for this reason the inclusion of the o-rings is warranted.

The average sound value for the modified roll-cages was 60 dB(A), when rotated for seven minutes on the carousel. This is significantly lower than the possible 66.6 dB(A) limit which may be considered by Dublin City Council.

Significant noise reductions were also achieved by the application of pieces of the hush-kit when the retro-fitted cages were folded for nesting inside the HGV trailer. The noise on dropping of the hinged floor onto the "A" frame was reduced by 9.4 dB(A) and the folding of the cage across the castor knuckles fitted with chamfered polymer plates, was reduced by 7.7 dB(A). However the absolute noise values for these events averaged 73 dB(A) which are above the proposed peak limit of 66.6 dB(A). From observations of a number of different deliveries however, it is expected that a trained operator could nest the cages more quietly and within the proposed peak limit of 66.6 dB(A). As recommended in chapter 5, suitable incentives and training modules could be devised to promote best practice by the logistics operatives.

The hush-kit applications reduced the noise caused by collisions with a wall, by 8.9 dB(A) for an empty cage and by 9.1 dB(A) for a loaded cage. While the absolute

values were again high at 75 dB(A), in practice, these impacts could be greatly mitigated or avoided by a trained operator.

The operatives employed by the Musgrave SuperValu Centra Group receive on the job training to ensure that they meet high standards of health and safety and that logistics and fuel efficiency targets are achieved. Drivers are instructed to switch off their HGV tractor unit engines when making kerb-side deliveries and to cause the minimum of noise disturbance. DIT has advised the company to add a new noise module to their driver training programme and to regularly monitor performance to ensure that standards are maintained.

The frequency spectra of the unmodified and modified roll-cages were also examined. The effectiveness of the hush-kit fitted to an empty roll-cage is illustrated in Figure 6.8. The roll-cage was fitted in the first instance with the full hush-kit package containing the o-rings, and then fitted with a kit which omitted the o-rings. The hush-kit package which included the o-ringed wheels (maroon lines) was more effective than that without the o-rings (yellow lines) applied to the wheels.

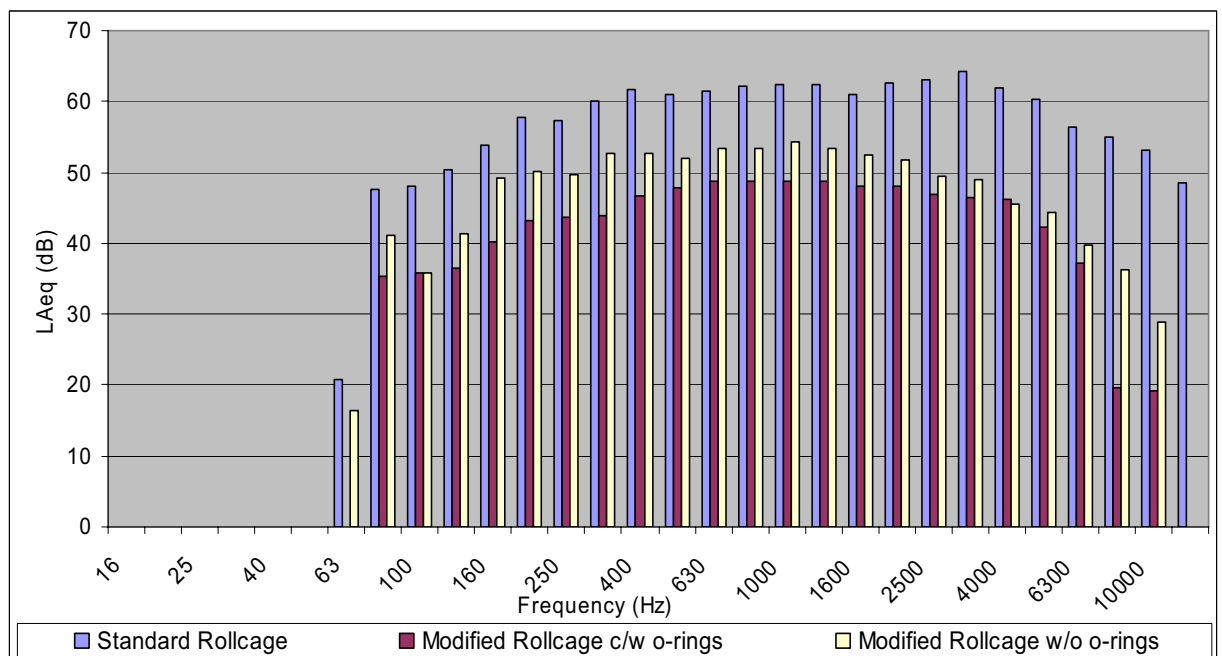


Figure 6.8. Three spectra of an empty roll-cage, (1) a standard cage (2) a modified roll-cage without o-rings fitted to the wheels and (3) a modified roll-cage with o-rings attached.

The effectiveness of applying the hush-kit to a loaded roll-cage across the frequency spectrum is illustrated in Figure 6.9. A significant attenuation was achieved evenly across the whole frequency range when a loaded hush-kit fitted roll-cage was rotated for seven minutes on the carousel, the greatest attenuation occurred at 6,300 Hz and above.

It is evident from an examination of Figures 6.8 and 6.9 that fitting the hush kit to both empty and the loaded cages was effective across all frequencies but had greatest impact at the higher end of the spectra above 6,300 Hz.

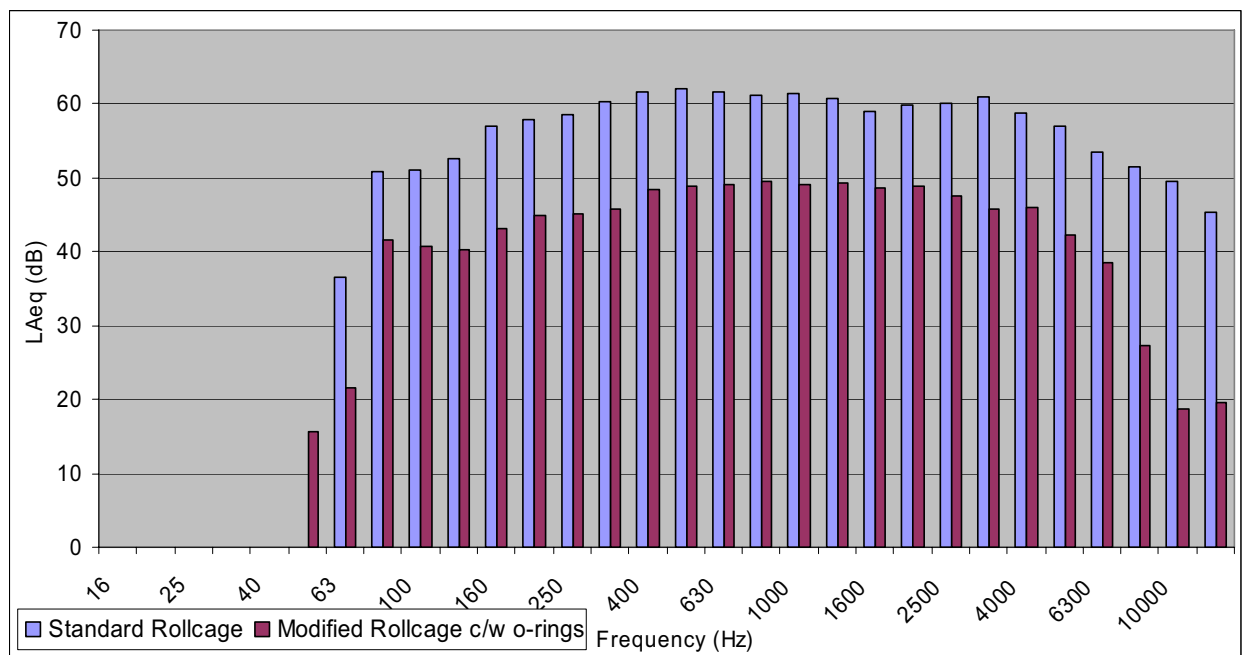


Figure 6.9. Noise reductions across the frequencies for a fully modified and “o-ringed” loaded cage compared with a standard loaded cage.

6.5. Cost of fitting a hush-kit

The hush-kits were manufactured cheaply from rubber off-cuts and from commercially available viscoelastic strips and adhesives and were easily retro-fitted. A time and motion study indicated that the total cost of preparing and applying a hush-kit including the o-rings, would amount to € 26. It is reasonable to assume that costs could be significantly reduced by series production. It is estimated that the additional cost to a distributor of “quietening” roll cages would add from 10 % to 15

% to the original price and that this operation could be included as a part of regular servicing.

6.6. Recommendation for further research

6.6.1. Further development of the acoustic coating

It was recognised that because of the high peak sound levels of up to 80 dB(A) experienced when the floor of the HGV trailer was impacted by the roll-cages, that a holistic approach was necessary to ensure conformance with the proposed noise limits. This involved a combination of the application of the acoustic coating, the attenuation of the roll-cage noises by the application of the hush-kit and changing operative behaviour. More developmental work is recommended to ensure that an optimal and cost effective solution is reached that is acceptable to all the parties affected by night deliveries.

The durability of the coating needs to be improved without diminishing its acoustic properties. The viscoelastic damping layer of the acoustic formulation was protected by a robust polyester top coat layer which was abraded by testing on the carousel to begin to reveal the softer black viscoelastic damping layer. The wear through of the hard top layer emerged after 20,000 cycles on the carousel which simulated the equivalent of 10 months in fleet service. This indicated that a thicker or harder polyester top coat will be necessary to ensure a longer and more acceptable in-service life of up to two years. It is a probability that the application of a more robust top coat ($> 150 \mu\text{m}$) above the viscoelastic water-based middle layer and aluminium primer, may compromise the acoustic effectiveness of the overall three layer formulation ($500 \mu\text{m}$ in total cross section). Further research to determine the optimum trade-offs between acoustic performance, durability and cost is recommended.

6.6.2. Further development of the hush kit

There is scope to bring the development of the hush-kit forward by (a) more analysis of the vibrating parts of the roll-cage and (b) by a deeper investigation of the best types of damping materials and adhesives available. There is also an opportunity to develop a similar hush kit for other ancillaries used during night delivery operations such as shopping and warehouse trolleys.

For example, acoustic arrays comprising a grid assembly of many microphones could be used to identify the vibrating characteristics of the different roll-cage components when the cage is mounted on the rotating carousel. Additional data could be generated by the use of an accelerometer and an Oberst vibrating bar. An analysis of this data would help to determine the optimum surface areas of the different roll-cage components that need to be treated with damping materials. It would also bring an acoustic consciousness to the design of a newer and quieter range of roll-cages. The trade-offs between quietness and cost could be more easily considered, for example in the design of the castors and wheel assemblies.

There is a need to ensure the best possible selection of the most appropriate damping rubbers and adhesives and to ensure optimum trade-offs between the acoustic properties, in service durability and costs. The effects of the retail environment, such as the carriage of chilled foodstuffs and of regular cleaning on the acoustic performance and durability of the damping materials selected, merits further investigation.

The proposed research would help to identify the particular components of roll-cages and trolleys which could be substituted with polymeric materials to reduce noise. This would apply for example, to the hinged floors and side frames which are folded during nesting, to the castor wheel assemblies and to the low noise tyres.

The hush kit merits further development to ensure that the most appropriate materials and adhesives are used in order to optimise the trade-off between acoustic performance, durability and costs. Whether suitable recyclable materials can be found

or whether it is necessary to source specially formulated materials and adhesives also merits further consideration.

Consideration should be given to injecting the hollow sections of the roll-cage frames with a porous melamine damping foam as suggested in chapter 2 (Jaouen, Renault and Deverge, 2007), and to comparing the acoustic results achieved.

6.6.3. Developing Virtual Acoustic Prototypes for rollcages and for related ancillaries.

In the field of acoustic design there has been considerable interest in developing “virtual acoustic prototypes” as a fast and cost effective means of trying out new designs. A machine that does not physically exist may be assembled by combining in the computer, sets of data that represent the appropriate vibro-acoustic properties of the separate components. The result may then be auralised to give a more or less realistic impression of the sound of the machine without the need to physically assemble it (Moorhouse and Seiffert, 2006).

This “virtual” technology has been used to predict the likely acoustic effects of changes to the designs of equipment such as tumble driers, lawn-mowers and automotive steering systems and it is suggested that this methodology might also be applied for the development of design modifications and hush-kits, leading to the more effective manufacture and availability of quieter rollcages and related ancillaries. This virtual technology might also be adapted to include shopping trolleys, hotel and hospital linen trolleys and refuse carts.

6.6.4. Improving the Damping Properties of the Panels

In the case of the aluminium and metal flooring panels of an HGV trailer and tail-gate platform, consideration should be given to perforating the panels with different patterns in order to change their natural frequencies and to reduce their effectiveness for radiating sound (Singapore Government, p. 75). While it may be acceptable to install a perforated HGV trailer floor for the carriage of ambient goods, this would not be suitable for chilled goods because of the need for frequent cleaning with detergents.

Consideration might also be given to securing the aluminium floors to the trailer under-frames by placing different thicknesses of plywood panels on the underside, and to comparing the resulting acoustic performances.

6.7. Optimising the interfaces between modifications to the roll-cages and coating the HGV floors and platforms to maximise acoustic performance

The promising research results as reported in Chapter 5, indicate that it may be possible to meet acceptable noise limits approaching 66.6 dB(A) by the application of hush-kits to the rollcages without recourse to acoustically coating the HGV trailer floors and tail-gate platforms. Further investigation is recommended of the interfaces between the mechanical and passive components with a view to optimising the noise reduction and cost trade-offs between modifications to the mechanical equipment on the one hand, and the treatment of the affected surfaces with an acoustic coating on the other. It may emerge that a sufficiently acoustically effective and robust hush-kits may be develop which could obviate the need to apply relatively expensive acoustic coatings to the trailer unit and tail lift platform of a HGV.

6.8. Anomalies

During the laboratory tests a characteristic resonance at 250 Hz appeared on all the spectra when the aluminium panels were impacted by the pendulum and by the falling weight. This anomaly was not experienced at the distribution depot test site. This will have been due to different natural frequencies induced in the two situations. The coating showing greater attenuation at a lower frequency of 1,600 Hz for mild steel and at a higher frequency of 2,500 Hz for aluminium and this is regarded as being related to the disparities in density, rigidity and cross section and patterns of the panels. These factors, which are the key to understanding vibration theory, will need to be considered fully and be carefully controlled in the planning and conduct of any further tests.

6.9. Training of operatives

All of the technical solutions proposed will need to be supported by suitable incentives and training courses for the logistics operatives to ensure that best practice guidelines are followed. As mentioned in 6.4, DIT has proposed providing suitable acoustic training modules for logistics service providers which could be readily incorporated into their ongoing training courses on health and safety and on achieving fuel and logistics efficiencies. Regular refresher courses and on the job performance monitoring will be necessary to ensure that satisfactory standards of low noise deliveries are maintained.

6.10. To conclude

The hypothesis has been established that *Acoustic materials are available or can be developed and applied to Heavy Goods Vehicles and ancillaries, which effectively and economically abate the noise caused by night deliveries*. Further research is desirable to further improve the availability of commercially viable and acoustically effective solutions acceptable to all the parties concerned.

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GLOSSARY OF TERMS

ASTM	American Society for Testing and Materials (Testing standards body in the USA).
B&K	Bruel and Kjaer (supplier of sound and vibration monitoring equipment).
BS	British Standards
CEC	Commission of the European Communities (European Commission)
CNMR	Centre for Nanotechnolgy and Materials Research (part of Athlone Institute of Technology).
CREST-DIT	Centre for Research in Engineering Surface Technology (part of the Dublin Institute of Technology).
CRTN	Calculation of Road Traffic Noise, Department of Transport and the Welsh Office, 1988 version.
DCC	Dublin City Council
EC	European Commission (Commission of the European Communities)
END	‘European Noise Directive’, short for the Assessment and Management of Environmental Noise’ Directive 2002/49/EC.
EPA	Environmental Protection Agency.
GIS	Geographical Information Systems: a system of computer software, hardware and data, and personnel to manipulate, analyse and present information that is geo-referenced (i.e. tied to a spatial location).
Hartwall	Manufacturer of rollcages used by the Musgraves chain of shops and supermarkets.
HGV	Heavy Goods Vehicle (i.e. Lorries) with a gross weight greater than 3.5 tonnes
HV	Heavy Vehicle (i.e. Lorries, buses, etc.) with a gross weight greater than 3.5 tonnes.
ISO	International Organisation for Standardisation
IPC	Integrated Pollution Control system.
Korva	Distributor of K.Hartwall rollcages within the UK.

L₁₀	The sound pressure level that is exceeded for 10% of the time for which the given sound is measured. The L ₁₀ is recognised as giving a better representation of people's reaction to traffic noise, than the LAeq parameter.
L₁₀ 1Hr	The L ₁₀ sound pressure level measured over a 1 hour period.
L₁₀ 18Hr	The arithmetic average of the L ₁₀ (1hr) levels for the 18 hour period between 6:00 am and 12:00 pm on a normal working day.
LAeq	The equivalent steady sound pressure level in decibels (dB) containing the same acoustic energy as the actual fluctuating sound level over a given period.
LA_{max}	Maximum sound level (using A-weighting)
LA_r	The equivalent continuous A-weighted sound pressure level during a specific time interval, plus specified adjustments for tonal characteristics and impulsiveness of the sound.
LA₉₀	This is a statistical value defined as the sound pressure level exceeded for 90% of a defined measurement period. In acoustical terms it represents the background sound level. It is measured in decibels.
LAF_{max}	It is the maximum A-weighted sound pressure value measured over a period of time. The data logging speed is "F" which stands for fast, and equates to a time constant of 0.125 seconds.
LAF₉₀	Also known as the background noise level, is the A-weighted sound pressure level of the residual noise at the assessment position that is exceeded for 90% of a given time interval, measured using fast time weighting, <i>F</i> , and quoted to the nearest whole number of decibels (BKSV, 2008).
L_{DEN}	Is the Day – Evening – Night noise indicator for overall annoyance. It is comprised of the average long term sound level of the all day period over a year, plus the average long term night time sound level, with a 10 decibel weighting as defined in END.
L_{Evening}	Is the noise index for annoyance during the evening period as defined in END.
LLF_{max}	Maximum sound level (using linear scale)
L_{Night}	Is the noise index for sleep disturbance as defined in END.
LV	Light Vehicles (i.e. cars, vans, etc) with the gross weight less than 3.5 tonnes.

Musgraves	Grocery wholesaler within Ireland and operate a chain of supermarkets and convenience shops, also referred to as MSVC (Musgraves Supervalu Centra).
Noise	This is defined simply as 'unwanted' sound.
NAS	Noise Abatement Society (it is a UK registered charity organisation that aims to eliminate excessive noise by raising awareness, lobbying parliament and through education).
NITL-DIT	National Institute of Transport and Logistics (part of the Dublin Institute of Technology).
PIEK / PEAK	Is a programme funded by the Ministry of Transport, Public Works and Water Management to reduce noise levels in the evening and night by the technical development and market introduction of 'silent' logistic equipment.
Pure Tones	A sound having a single frequency whose sound pressure varies sinusoidally with time. A tone with no harmonics. All energy is concentrated at a single frequency. The sound pressure is a simple sinusoidal function of the time, and characterised by its singleness of pitch. (Bruel and Kjaer, 2008)
Rollcage	Wheeled metal framed container generally with cage like sides used for the carriage of goods from trucks to shops.
SCATS	Sydney Coordinated Adaptive Traffic System is an intelligent transportation system, which uses traffic cameras or induction loops installed within the road pavement to count vehicles at each intersection, and adapts the timing through a central computer.
Shape-file	A Shape-file stores non-topological geometry and attribute information for the spatial features in a data set. The geometry for a feature is stored as a shape comprising a set of vector coordinates.
SPC	Special Policy Committee on Transportation and Traffic from Dublin City Council.
TNO	Netherlands Organisation for Applied Scientific Research
Tail-lift	Mechanically operated metal platform attached to the rear of trailers that is used for the loading and unloading of goods.
Traffic Flow	The average number of vehicles passing along a link or road in one hour periods over 24 hours.
TRL	Transport Research Laboratory (in the UK).

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APPENDIX

Appendix I – Analysis of field trials (Chapter 3)

I.0. Background noise verses specific noise

Four stores were selected and the peak noise events taking place during the deliveries were recorded. The acoustic data was monitored in accord with BS 4142 and graphic data was also recorded using a night vision camera in order to identify the events and equipment that caused most disturbances. The specific noise recorded during the deliveries to stores A B C and D is described graphically in the charts below and are compared with the background noise at these respective locations.

STORE A

Background Noise:

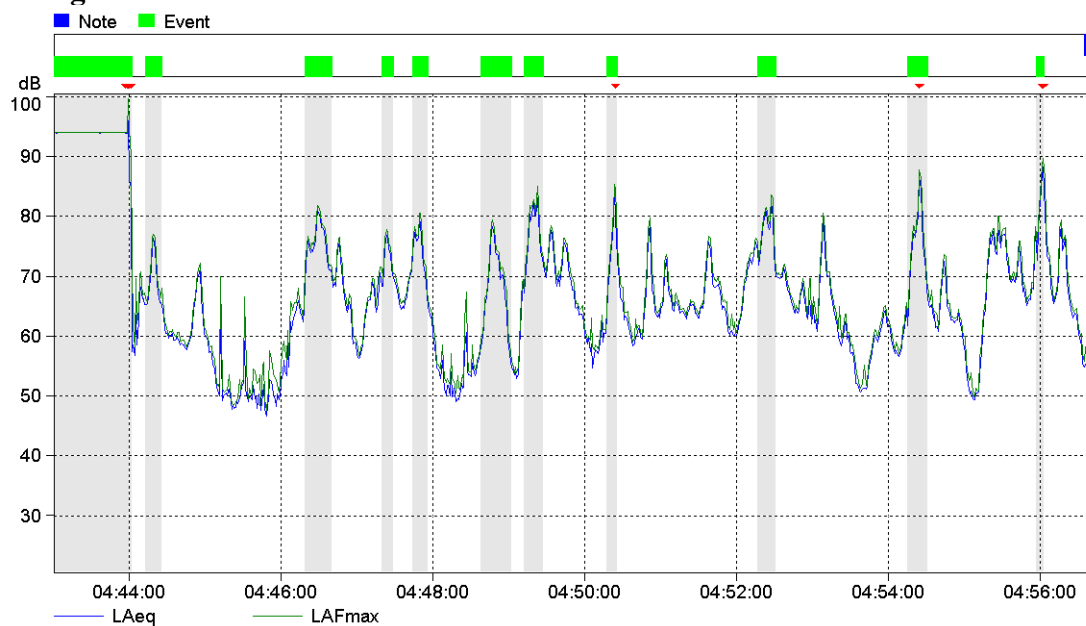


Figure I.1. Datalog showing the background noise for store A, LA_{eq} measured at 1sec intervals

Table I.1. Details of the events shown above in Figure I.1 for the background noise for store A, LA_{eq} measured at 1sec intervals

Name	Start time	End time	Duration	LAeq [dB]	LAF90 [dB]	LAFmax [dB]	Remarks
Total	24/03/2006 04:43:01	24/03/2006 04:56:39	0:13:38	82.9	52.2	99.6	
Unmarked	24/03/2006 04:44:03	24/03/2006 04:56:35	0:10:04	67.8	50.9	80.5	
(All) Note	24/03/2006 04:56:35	24/03/2006 04:56:39	0:00:04	54.2	52.9	58.1	
(All) Event	24/03/2006 04:43:01	24/03/2006 04:56:04	0:03:30	88.7	66.6	99.6	
Note	24/03/2006 04:56:35	24/03/2006 04:56:39	0:00:04	54.2	52.9	58.1	Rain, spray from tyres, 6 C, batt. replaced
Event	24/03/2006 04:43:01	24/03/2006 04:44:03	0:01:02	93.8	93.8	99.6	Big mechanical forklift
Event	24/03/2006 04:44:13	24/03/2006 04:44:27	0:00:14	70.9	65.1	76.9	Car passing
Event	24/03/2006 04:46:19	24/03/2006 04:46:41	0:00:22	76.3	70.8	81.7	cars passing
Event	24/03/2006 04:47:20	24/03/2006 04:47:30	0:00:10	73.6	69.3	77.8	car passing
Event	24/03/2006 04:47:44	24/03/2006 04:47:57	0:00:13	75.3	66.7	80.6	van passing
Event	24/03/2006 04:48:38	24/03/2006 04:49:03	0:00:25	71.7	57.4	79.3	car passing
Event	24/03/2006 04:49:12	24/03/2006 04:49:28	0:00:16	78.5	70.7	84.9	truck passing
Event	24/03/2006 04:50:18	24/03/2006 04:50:27	0:00:09	77.9	68.4	85.3	truck passing
Event	24/03/2006 04:52:17	24/03/2006 04:52:32	0:00:15	78.1	71.5	83.6	truck passing
Event	24/03/2006 04:54:15	24/03/2006 04:54:32	0:00:17	78.8	65.1	87.8	delivery truck arrives
Event	24/03/2006 04:55:57	24/03/2006 04:56:04	0:00:07	84.0	73.2	89.6	2nd delivery truck arrives

Specific Noise:

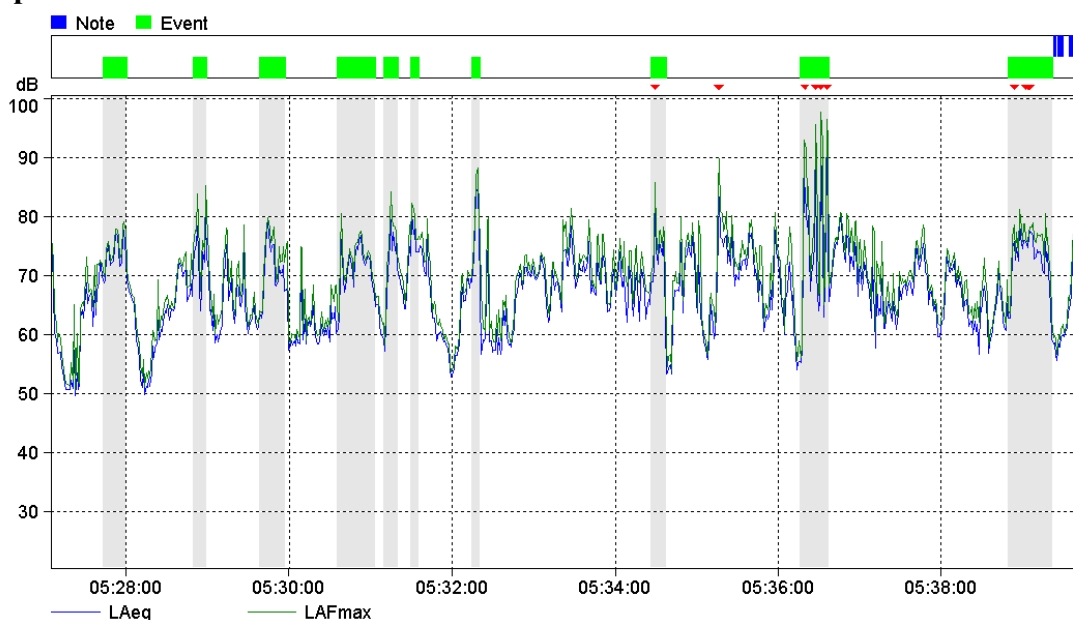


Figure I.2. Datalog showing the specific noise for store A, LA_{eq} measured at 1sec intervals

Table I.2. Details of the events shown above in Figure I.2 for the specific event noise for store A, LA_{eq} measured at 1sec intervals

Name	Start time	End time	Duration	LAeq [dB]	LAF90 [dB]	LAFmax [dB]	Remarks
Total	24/03/2006 05:27:05	24/03/2006 05:39:44	0:12:39	72.8	57.8	97.7	
Unmarked	24/03/2006 05:27:05	24/03/2006 05:39:39	0:09:35	69.3	57.1	89.8	
(All) Note	24/03/2006 05:39:26	24/03/2006 05:39:44	0:00:13	75.4	58.0	82.1	
(All) Event	24/03/2006 05:27:43	24/03/2006 05:39:23	0:02:51	77.3	63.3	97.7	
Note	24/03/2006 05:39:26	24/03/2006 05:39:30	0:00:04	59.0	57.4	61.7	2 HGV's delivered 14 roll cages each
Note	24/03/2006 05:39:34	24/03/2006 05:39:38	0:00:04	72.4	63.9	76.8	Conditions: 8 degrees C, light rain
Note	24/03/2006 05:39:39	24/03/2006 05:39:44	0:00:05	78.8	75.9	82.1	Total dwell time 19:12, 4min. lost in reloading batt.
Event	24/03/2006 05:27:43	24/03/2006 05:28:01	0:00:18	74.0	69.1	79.0	tail lift down with full rollcages
Event	24/03/2006 05:28:49	24/03/2006 05:29:00	0:00:11	74.6	63.7	85.3	rollcages from tail lift to pavement
Event	24/03/2006 05:29:38	24/03/2006 05:29:58	0:00:20	72.8	63.2	79.7	handling full rollcages
Event	24/03/2006 05:30:35	24/03/2006 05:31:04	0:00:29	72.2	64.9	80.3	handling full rollcages
Event	24/03/2006 05:31:10	24/03/2006 05:31:21	0:00:11	74.2	59.6	84.0	handling full rollcages
Event	24/03/2006 05:31:29	24/03/2006 05:31:36	0:00:07	76.6	72.3	82.2	handling full rollcages
Event	24/03/2006 05:32:14	24/03/2006 05:32:21	0:00:07	80.1	68.2	88.1	loading empty rollcages on tailgate
Event	24/03/2006 05:34:26	24/03/2006 05:34:38	0:00:12	74.5	62.6	85.6	tail lift up with empty rollcages
Event	24/03/2006 05:36:16	24/03/2006 05:36:38	0:00:22	83.6	58.8	97.7	lifting tail lift and folding lugs
Event	24/03/2006 05:38:49	24/03/2006 05:39:23	0:00:34	74.1	62.8	81.2	start engine and drives off

STORE B

Background Noise:

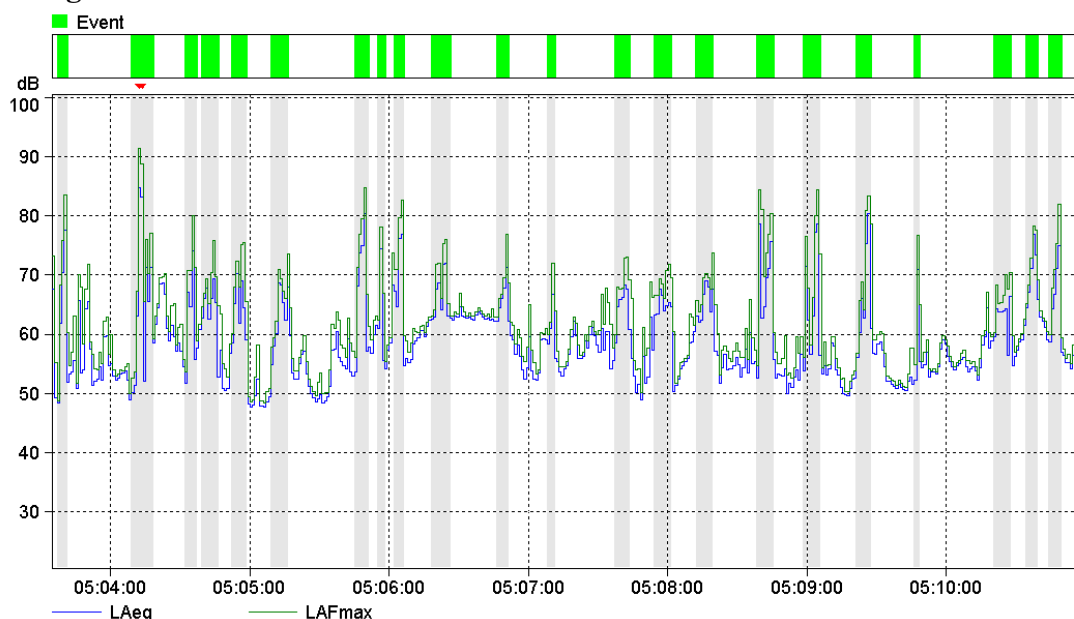


Figure I.3. Datalog showing the background noise for store B, LAeq measured at 1sec intervals

Table I.3. Details of the events shown above in Figure I.3 for the background noise for store B, LAeq measured at 1sec intervals

Name	Start time	End time	Duration	LAeq [dB]	LAF90 [dB]	LAFmax [dB]	Remarks
Total	10/03/2006 05:03:35	10/03/2006 05:10:59	0:07:24	66.5	50.8	91.3	
Unmarked	10/03/2006 05:03:42	10/03/2006 05:10:59	0:04:54	58.2	50.1	73.8	
(All) Note	10/03/2006 05:03:35	10/03/2006 05:03:37	0:00:02	64.5	48.4	73.1	
(All) Event	10/03/2006 05:03:37	10/03/2006 05:10:50	0:02:28	70.8	54.2	91.3	
Note	10/03/2006 05:03:35	10/03/2006 05:03:37	0:00:02	64.5	48.4	73.1	Conditions: 4 degrees C, dry, medium wind speeds
Event	10/03/2006 05:03:37	10/03/2006 05:03:42	0:00:05	71.4	48.3	83.6	Passing traffic
Event	10/03/2006 05:04:09	10/03/2006 05:04:19	0:00:10	77.2	50.0	91.3	Passing traffic
Event	10/03/2006 05:04:32	10/03/2006 05:04:38	0:00:06	67.6	51.6	80.0	Passing traffic
Event	10/03/2006 05:04:39	10/03/2006 05:04:47	0:00:08	65.7	57.8	75.7	Passing traffic
Event	10/03/2006 05:04:52	10/03/2006 05:04:59	0:00:07	65.9	55.6	75.4	Passing traffic
Event	10/03/2006 05:05:09	10/03/2006 05:05:17	0:00:08	65.3	56.3	73.4	Passing traffic
Event	10/03/2006 05:05:45	10/03/2006 05:05:52	0:00:07	73.9	54.3	84.7	Passing traffic
Event	10/03/2006 05:05:55	10/03/2006 05:05:59	0:00:04	68.6	53.3	78.0	Passing traffic
Event	10/03/2006 05:06:02	10/03/2006 05:06:07	0:00:05	73.0	54.9	82.6	Passing traffic
Event	10/03/2006 05:06:18	10/03/2006 05:06:27	0:00:09	67.8	62.5	76.0	Passing traffic
Event	10/03/2006 05:06:46	10/03/2006 05:06:52	0:00:06	66.9	61.5	76.8	Passing traffic
Event	10/03/2006 05:07:08	10/03/2006 05:07:12	0:00:04	62.4	58.1	71.9	Passing traffic
Event	10/03/2006 05:07:37	10/03/2006 05:07:44	0:00:07	65.5	57.3	72.9	Passing traffic
Event	10/03/2006 05:07:54	10/03/2006 05:08:02	0:00:08	65.1	57.2	71.7	Passing traffic
Event	10/03/2006 05:08:12	10/03/2006 05:08:20	0:00:08	66.0	60.6	73.8	Passing traffic
Event	10/03/2006 05:08:38	10/03/2006 05:08:46	0:00:08	72.2	52.3	84.4	Passing traffic
Event	10/03/2006 05:08:58	10/03/2006 05:09:06	0:00:08	72.5	54.1	84.3	Passing traffic
Event	10/03/2006 05:09:21	10/03/2006 05:09:28	0:00:07	73.3	55.8	83.4	Passing traffic
Event	10/03/2006 05:09:46	10/03/2006 05:09:49	0:00:03	66.2	50.4	76.6	Passing traffic
Event	10/03/2006 05:10:20	10/03/2006 05:10:28	0:00:08	63.6	57.6	70.3	Passing traffic
Event	10/03/2006 05:10:34	10/03/2006 05:10:40	0:00:06	71.9	64.2	78.2	Passing traffic
Event	10/03/2006 05:10:44	10/03/2006 05:10:50	0:00:06	69.4	56.7	82.0	Passing traffic

Specific Noise:

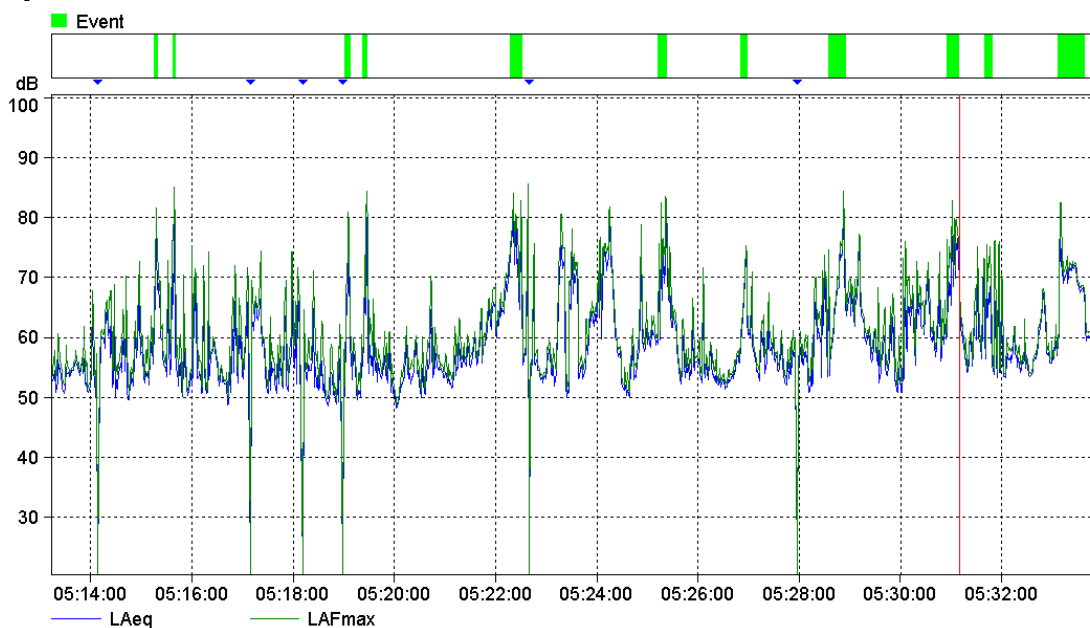


Figure I.4. Datalog showing the specific noise for store B, LA_{eq} measured at 1sec intervals

Table I.4. Details of the events shown above in Figure I.4 for the specific noise events for store B, LA_{eq} measured at 1sec intervals

Name	Start time	End time	Duration	LAeq [dB]	LAFmax [dB]	Remarks
Total	10/03/2006 05:13:14	10/03/2006 05:33:50	0:20:36	65.5	85.6	
Unmarked	10/03/2006 05:13:14	10/03/2006 05:33:50	0:18:23	62.3	85.6	
(All) Event	10/03/2006 05:15:15	10/03/2006 05:33:39	0:02:13	72.7	85.1	
Event	10/03/2006 05:15:15	10/03/2006 05:15:20	0:00:05	73.6	81.8	3 Full roll cages moving from tail lift onto pavement
Event	10/03/2006 05:15:37	10/03/2006 05:15:41	0:00:04	75.3	85.1	3 Full roll cages moving from tail lift onto pavement
Event	10/03/2006 05:19:01	10/03/2006 05:19:08	0:00:07	71.1	80.9	Roll cage moving from tail lift onto pavement
Event	10/03/2006 05:19:23	10/03/2006 05:19:29	0:00:06	74.0	84.3	Roll cage moving from tail lift onto pavement
Event	10/03/2006 05:22:17	10/03/2006 05:22:32	0:00:15	75.4	84.0	Roll cage moving from tail lift onto pavement
Event	10/03/2006 05:25:13	10/03/2006 05:25:24	0:00:11	75.4	83.5	Tail lift moving downwards & passerby shouting
Event	10/03/2006 05:26:51	10/03/2006 05:26:59	0:00:08	68.5	75.3	Full roll cages moving along pavement
Event	10/03/2006 05:28:35	10/03/2006 05:28:56	0:00:21	72.6	84.3	12 Empty roll cages moving from pavement onto tail lift
Event	10/03/2006 05:30:55	10/03/2006 05:31:10	0:00:15	72.7	82.8	Empty roll cages moving from tail lift into body
Event	10/03/2006 05:31:40	10/03/2006 05:31:49	0:00:09	65.4	75.5	Empty roll cages moving from tail lift into body
Event	10/03/2006 05:33:07	10/03/2006 05:33:39	0:00:32	70.5	82.4	Trailer door closing & tail lift folding into underslung position

STORE C

Background Noise:

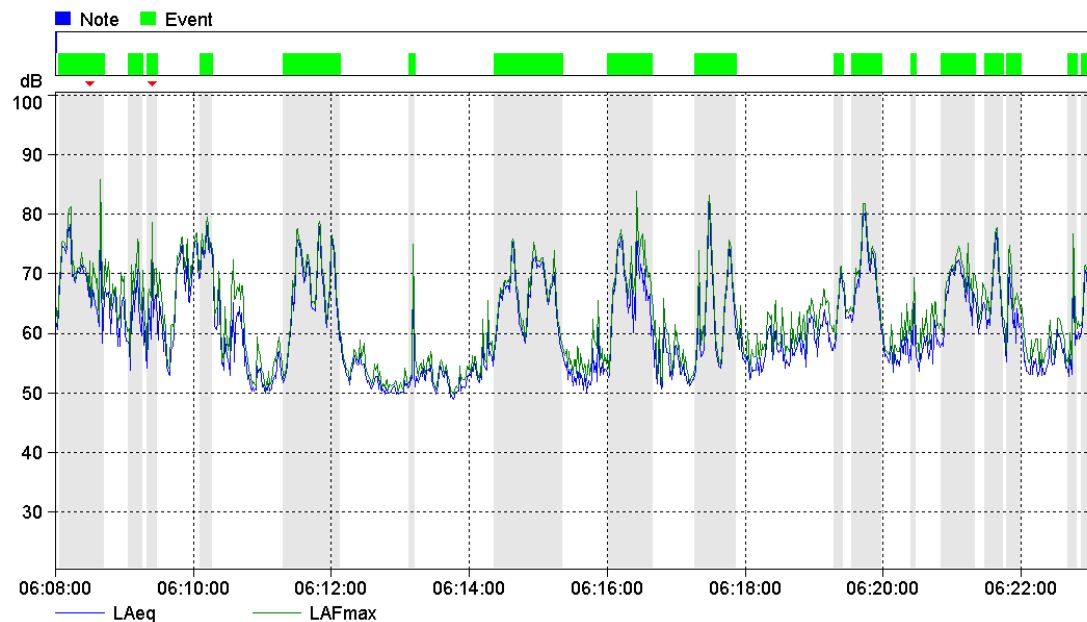


Figure I.5. Datalog showing the background noise for store C, LAeq measured at 1sec intervals

Table I.5. Details of the events shown above in Figure I.5 for the background noise for store C, LAeq measured at 1sec intervals

Name	Start time	End time	Duration	LAeq [dB]	LAFmax [dB]	Remarks
Total	10/03/2006 06:08:00	10/03/2006 06:23:00	0:15:00	67.0	85.7	
Unmarked	10/03/2006 06:08:02	10/03/2006 06:23:00	0:08:29	60.9	76.8	
(All) Note	10/03/2006 06:08:00	10/03/2006 06:08:02	0:00:02	61.1	64.3	
(All) Event	10/03/2006 06:08:03	10/03/2006 06:22:59	0:06:29	70.0	85.7	
Note	10/03/2006 06:08:00	10/03/2006 06:08:02	0:00:02	61.1	64.3	Conditions: 4 degrees C, dry, medium wind speeds
Event	10/03/2006 06:08:03	10/03/2006 06:08:43	0:00:40	72.0	85.7	Passing traffic
Event	10/03/2006 06:09:03	10/03/2006 06:09:17	0:00:14	65.2	75.8	Passing traffic
Event	10/03/2006 06:09:19	10/03/2006 06:09:29	0:00:10	65.4	78.5	Passing traffic
Event	10/03/2006 06:10:05	10/03/2006 06:10:17	0:00:12	74.4	79.4	Van passing
Event	10/03/2006 06:11:18	10/03/2006 06:12:08	0:00:50	70.5	78.8	Passing traffic
Event	10/03/2006 06:13:07	10/03/2006 06:13:13	0:00:06	61.6	74.9	Passing traffic
Event	10/03/2006 06:14:21	10/03/2006 06:15:22	0:01:01	68.4	75.8	Passing traffic
Event	10/03/2006 06:16:00	10/03/2006 06:16:40	0:00:40	70.1	83.7	Passing traffic
Event	10/03/2006 06:17:16	10/03/2006 06:17:53	0:00:37	70.5	83.0	Passing traffic
Event	10/03/2006 06:19:17	10/03/2006 06:19:26	0:00:09	68.7	71.2	Passing traffic
Event	10/03/2006 06:19:32	10/03/2006 06:19:59	0:00:27	72.7	81.8	Passing traffic
Event	10/03/2006 06:20:24	10/03/2006 06:20:29	0:00:05	60.8	69.3	Passing traffic
Event	10/03/2006 06:20:50	10/03/2006 06:21:21	0:00:31	68.4	75.0	Passing traffic
Event	10/03/2006 06:21:28	10/03/2006 06:21:45	0:00:17	70.2	77.6	Bus passing
Event	10/03/2006 06:21:47	10/03/2006 06:22:01	0:00:14	64.6	74.8	Passing traffic
Event	10/03/2006 06:22:40	10/03/2006 06:22:49	0:00:09	63.7	76.6	Passing traffic
Event	10/03/2006 06:22:52	10/03/2006 06:22:59	0:00:07	68.1	71.4	Passing traffic

Specific Noise:

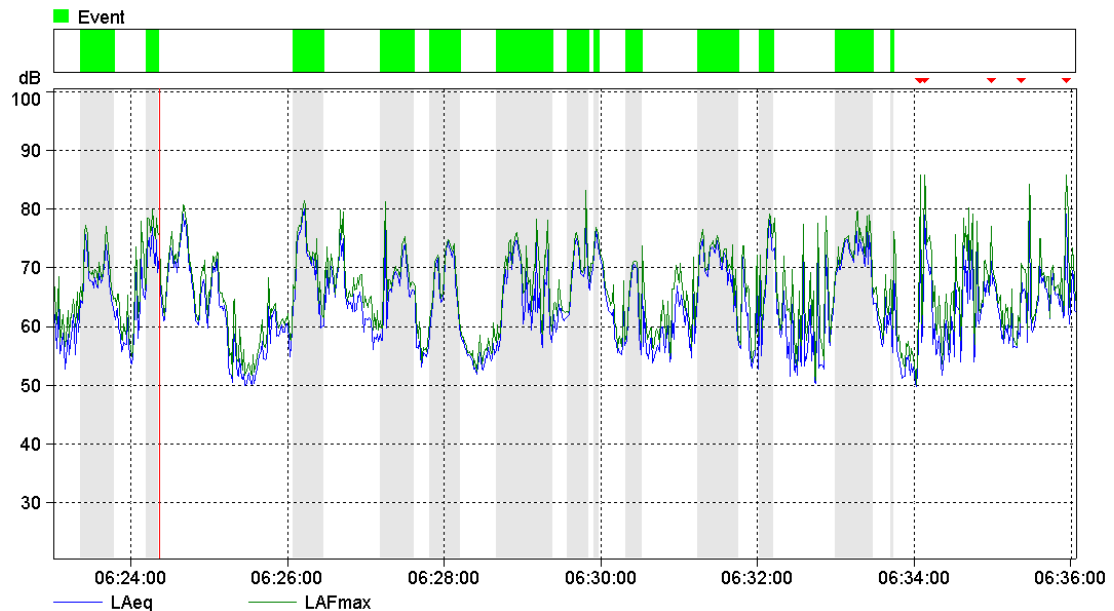


Figure I.6. Datalog showing the specific noise for store C, LAeq measured at 1sec intervals

Table I.6. Details of the events shown above in Figure I.6 for the specific event noise for store C, LA_{eq} measured at 1sec intervals

Name	Start time	End time	Duration	LA _{eq} [dB]	LAF _{max} [dB]	Remarks
Total	10/03/2006 06:23:01	10/03/2006 06:36:04	0:13:03	68.4	85.7	
Unmarked	10/03/2006 06:23:01	10/03/2006 06:36:04	0:08:35	65.9	85.7	
(All) Event	10/03/2006 06:23:21	10/03/2006 06:33:45	0:04:28	71.0	83.2	
Event	10/03/2006 06:23:21	10/03/2006 06:23:48	0:00:27	69.4	77.1	rollcages crossing road
Event	10/03/2006 06:24:12	10/03/2006 06:24:22	0:00:10	73.4	79.8	Rollcages banging against kerb
Event	10/03/2006 06:26:04	10/03/2006 06:26:28	0:00:24	73.4	81.3	tailgate going up
Event	10/03/2006 06:27:11	10/03/2006 06:27:38	0:00:27	69.1	81.2	tailgate down with full rolcages
Event	10/03/2006 06:27:49	10/03/2006 06:28:13	0:00:24	69.7	74.7	moving cages across street
Event	10/03/2006 06:28:40	10/03/2006 06:29:24	0:00:44	68.9	78.1	returning empty cages to truck
Event	10/03/2006 06:29:34	10/03/2006 06:29:51	0:00:17	71.7	83.2	empty cages onto tailgate
Event	10/03/2006 06:29:54	10/03/2006 06:29:59	0:00:05	74.0	76.8	tailgate going up & lugs folded
Event	10/03/2006 06:30:19	10/03/2006 06:30:32	0:00:13	67.5	73.8	empty cages moved to back of trailer
Event	10/03/2006 06:31:14	10/03/2006 06:31:48	0:00:32	71.0	76.5	organising cages within trailer
Event	10/03/2006 06:32:01	10/03/2006 06:32:13	0:00:12	72.7	79.1	organising cages within trailer
Event	10/03/2006 06:32:59	10/03/2006 06:33:29	0:00:30	72.6	79.6	closing doors & folding tailgate underneath
Event	10/03/2006 06:33:42	10/03/2006 06:33:45	0:00:03	65.4	76.1	starting engine & driving off

STORE D

Background Noise:

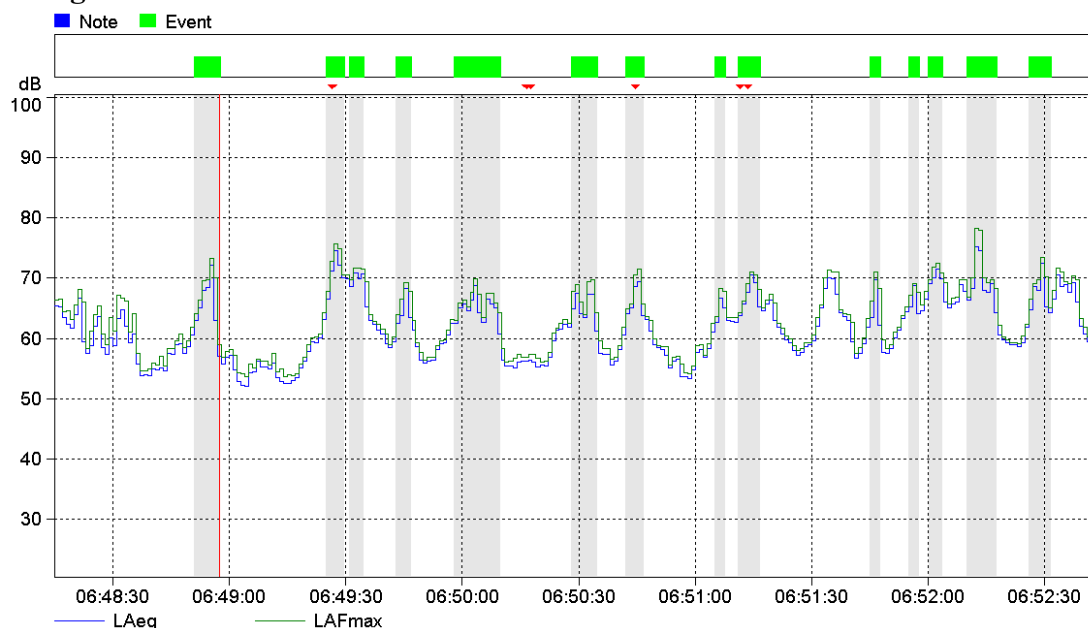


Figure I.7. Datalog showing the background noise for store D, LA_{eq} measured at 1sec intervals

Table I.7. Details of the events shown above in Figure I.7 for the background noise for store D, LA_{eq} measured at 1sec intervals

Name	Start time	End time	Duration	LAeq [dB]	LAF90 [dB]	LAFmax [dB]	Remarks
Total	22/06/2006 06:48:15	22/06/2006 06:52:44	0:04:29	64.7	55.1	78.2	
Unmarked	22/06/2006 06:48:15	22/06/2006 06:52:43	0:03:11	61.9	54.5	71.5	
(All) Note	22/06/2006 06:52:43	22/06/2006 06:52:44	0:00:01	59.5	59.1	60.4	
(All) Event	22/06/2006 06:48:51	22/06/2006 06:52:32	0:01:17	68.1	62.5	78.2	
Note	22/06/2006 06:52:43	22/06/2006 06:52:44	0:00:01	59.5	59.1	60.4	Weather: dry, 10C, high wind speed
Event	22/06/2006 06:48:51	22/06/2006 06:48:58	0:00:07	67.3	57.5	73.3	Passing traffic
Event	22/06/2006 06:49:25	22/06/2006 06:49:30	0:00:05	71.6	65.5	75.6	passing bus
Event	22/06/2006 06:49:31	22/06/2006 06:49:35	0:00:04	70.1	68.3	71.6	passing car
Event	22/06/2006 06:49:43	22/06/2006 06:49:47	0:00:04	65.1	61.7	69.3	passing car
Event	22/06/2006 06:49:58	22/06/2006 06:50:10	0:00:12	65.3	62.3	69.8	3 passing cars
Event	22/06/2006 06:50:28	22/06/2006 06:50:35	0:00:07	65.6	62.1	69.6	2 passing cars
Event	22/06/2006 06:50:42	22/06/2006 06:50:47	0:00:05	66.8	63.5	71.4	passing car
Event	22/06/2006 06:51:05	22/06/2006 06:51:08	0:00:03	65.1	62.3	68.2	passing car
Event	22/06/2006 06:51:11	22/06/2006 06:51:17	0:00:06	67.6	63.7	71.1	2 passing cars
Event	22/06/2006 06:51:45	22/06/2006 06:51:48	0:00:03	66.4	60.9	70.9	passing car
Event	22/06/2006 06:51:55	22/06/2006 06:51:58	0:00:03	66.5	63.7	69.1	passing car
Event	22/06/2006 06:52:00	22/06/2006 06:52:04	0:00:04	70.2	68.5	72.4	3 passing cars
Event	22/06/2006 06:52:10	22/06/2006 06:52:18	0:00:08	70.7	66.0	78.2	2 passing cars
Event	22/06/2006 06:52:26	22/06/2006 06:52:32	0:00:06	68.2	63.2	73.4	3 passing cars

Specific Noise:

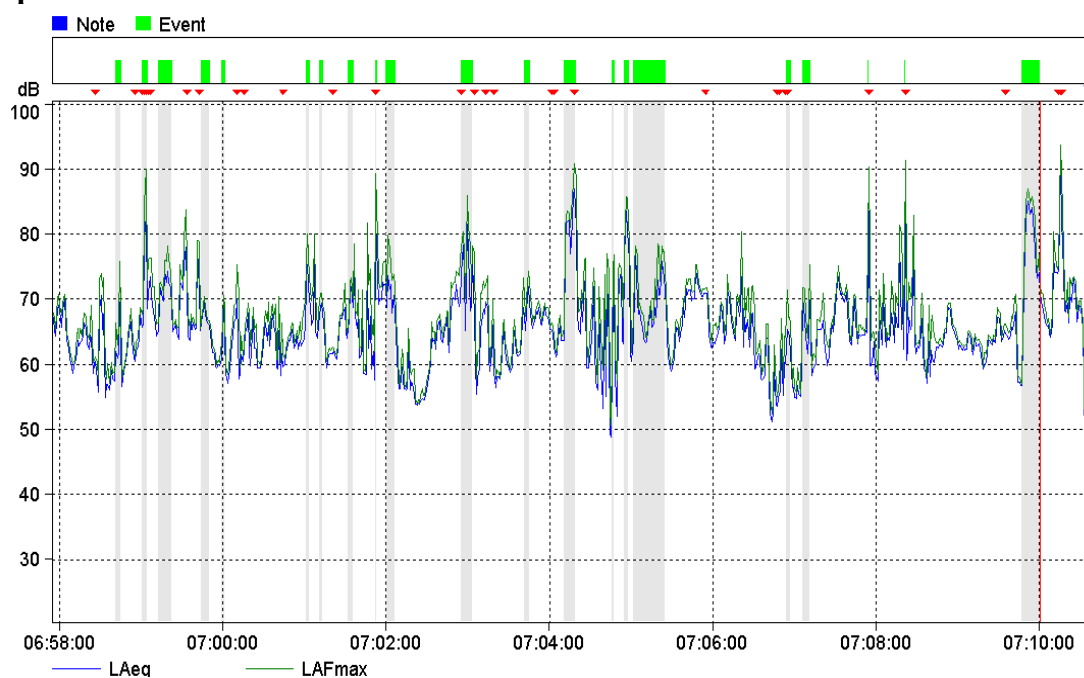


Figure I.8. Datalog showing the specific noise for store D, LA_{eq} measured at 1sec intervals

Table I.8. Details of the events shown above in Figure I.8 for the specific event noise for store D, LA_{eq} measured at 1sec intervals

Name	Start time	End time	Duration	LAeq [dB]	LAF90 [dB]	LAFmax [dB]	Remarks
Total	22/06/2006 06:57:55	22/06/2006 07:10:41	0:12:46	71.2	57.6	93.8	
Unmarked	22/06/2006 06:57:55	22/06/2006 07:10:40	0:10:38	68.1	57.2	93.8	
(All) Note	22/06/2006 07:10:40	22/06/2006 07:10:41	0:00:01	58.8	58.4	59.4	
(All) Event	22/06/2006 06:58:41	22/06/2006 07:10:01	0:02:07	76.8	63.1	91.2	
Note	22/06/2006 07:10:40	22/06/2006 07:10:41	0:00:01	58.8	58.4	59.4	Conditions: dry, 10 degrees C, high wind speeds
Event	22/06/2006 06:58:41	22/06/2006 06:58:46	0:00:05	64.5	56.1	75.8	Full rollcages moving onto tail lift from truck body
Event	22/06/2006 06:59:01	22/06/2006 06:59:05	0:00:04	78.7	63.9	89.9	Lugs folded down with full cages moving along pavement
Event	22/06/2006 06:59:13	22/06/2006 06:59:23	0:00:10	71.9	68.6	78.2	Full roll cage moving along pavement
Event	22/06/2006 06:59:44	22/06/2006 06:59:51	0:00:07	67.4	65.8	70.4	Tail lift moving upwards with no roll cages
Event	22/06/2006 06:59:59	22/06/2006 07:00:02	0:00:03	65.8	60.2	70.6	Full roll cages moving from trailer body onto tail lift
Event	22/06/2006 07:01:01	22/06/2006 07:01:04	0:00:03	73.0	69.0	80.1	Full roll cages moving from tail lift onto pavement
Event	22/06/2006 07:01:11	22/06/2006 07:01:14	0:00:03	68.7	67.0	70.9	Full roll cage moving along pavement to store & passing traffic
Event	22/06/2006 07:01:32	22/06/2006 07:01:37	0:00:05	71.2	66.7	78.5	Passing bus
Event	22/06/2006 07:01:52	22/06/2006 07:01:54	0:00:02	79.7	55.0	89.2	Door of 'pay&display' box closing
Event	22/06/2006 07:02:00	22/06/2006 07:02:07	0:00:07	70.8	66.1	79.8	Full roll cages moving along pavement to store
Event	22/06/2006 07:02:55	22/06/2006 07:03:04	0:00:09	78.1	64.8	86.0	Empty roll cages moving from footpath onto tail lift
Event	22/06/2006 07:03:42	22/06/2006 07:03:46	0:00:04	69.9	64.7	74.4	Full roll cage moving along pavement to store
Event	22/06/2006 07:04:11	22/06/2006 07:04:20	0:00:09	82.7	75.7	90.9	Empty roll cages moving along pavement to truck
Event	22/06/2006 07:04:46	22/06/2006 07:04:48	0:00:02	71.1	49.5	76.8	Securing of empty roll cages on tail lift
Event	22/06/2006 07:04:55	22/06/2006 07:04:59	0:00:04	80.3	75.2	85.8	Securing of empty roll cages on tail lift
Event	22/06/2006 07:05:02	22/06/2006 07:05:26	0:00:24	70.7	64.0	78.5	Tail lift moving upwards with empty roll cages
Event	22/06/2006 07:06:54	22/06/2006 07:06:58	0:00:04	64.3	58.4	71.3	Noise from inside the trailer body (cages moving around)
Event	22/06/2006 07:07:06	22/06/2006 07:07:12	0:00:06	67.4	60.4	75.3	Noise from inside the trailer body (cages moving around)
Event	22/06/2006 07:07:54	22/06/2006 07:07:55	0:00:01	83.6	60.2	90.2	Folding of tail lift lugs
Event	22/06/2006 07:08:21	22/06/2006 07:08:22	0:00:01	85.8	70.0	91.2	Folding of tail lift lugs
Event	22/06/2006 07:09:47	22/06/2006 07:10:01	0:00:14	80.6	66.2	86.9	Truck driven away

I.1. Selected spectra for specific events

The spectra follow the sequence of events for the off loading of the roll-cages from the HGV trailer and replacing the empty cages onto the trailer as follows. The loaded roll-cages were manipulated inside the trailer, the rollcages were then moved from the trailer (aluminium floor) on to the tail lift (mild steel floor), the roll-cages were then moved from the tail-lift onto the roadway, the roll-cages were then mounted on to the kerb and were pushed along the pavement into the store. Empty roll-cages were then pushed along the pavement towards and onto the tail lift and then from the tail lift into the trailer body where they were stacked and secured.

Examples of spectra are given below for stores A, B and D. Events relating to store C are given as examples in the main chapter.

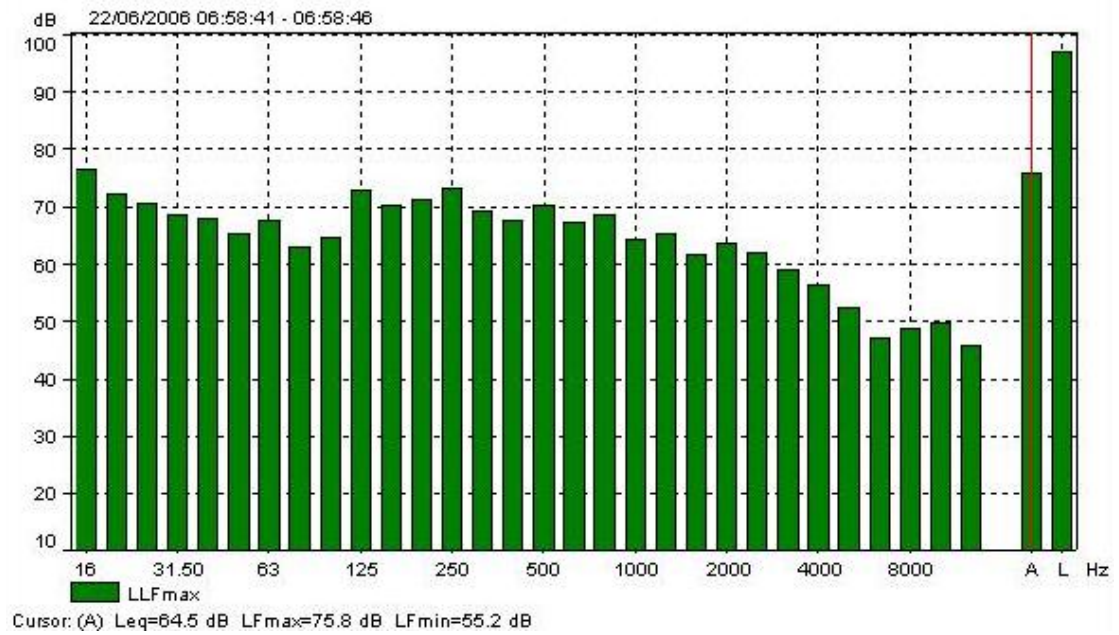


Figure I.9. Moving filled roll-cages from the trailer onto the tail-lift at store D

The frequencies were concentrated across the lower ranges.

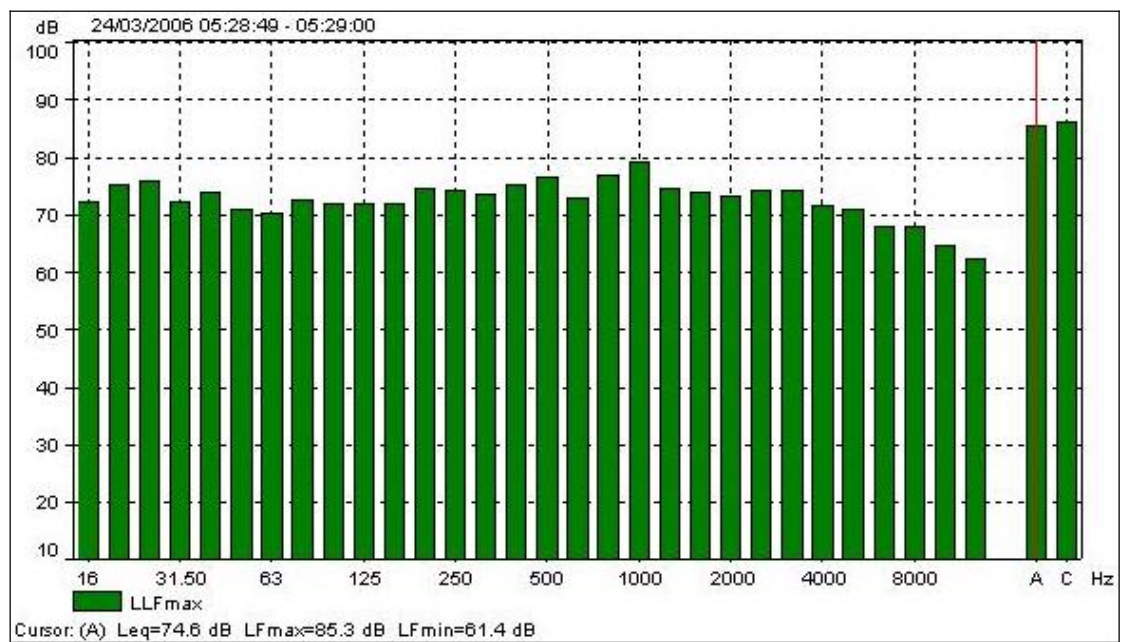


Figure I.10. Moving full roll-cages onto the pavement at store A

The full roll cages moving from the tail lift onto the pavement showed a fairly even spread across the frequencies.

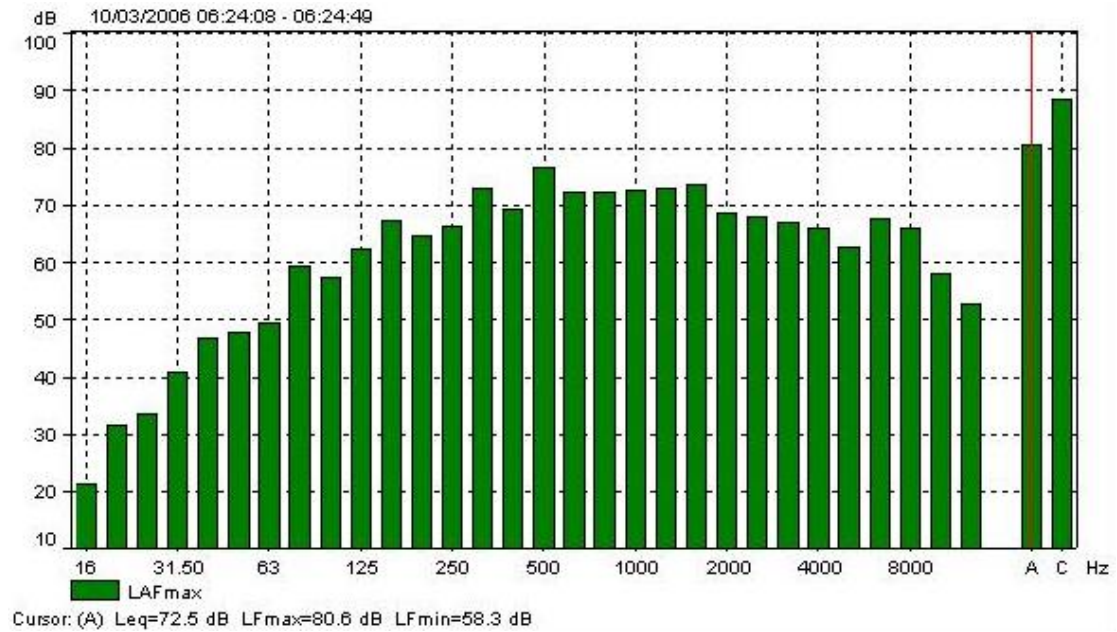


Figure I.11. Mounting the kerb with a full roll-cage at store C

Frequencies were in the mid to higher ranges, particularly at 315 Hz and 500 Hz. The low frequencies showed low sound pressure levels.

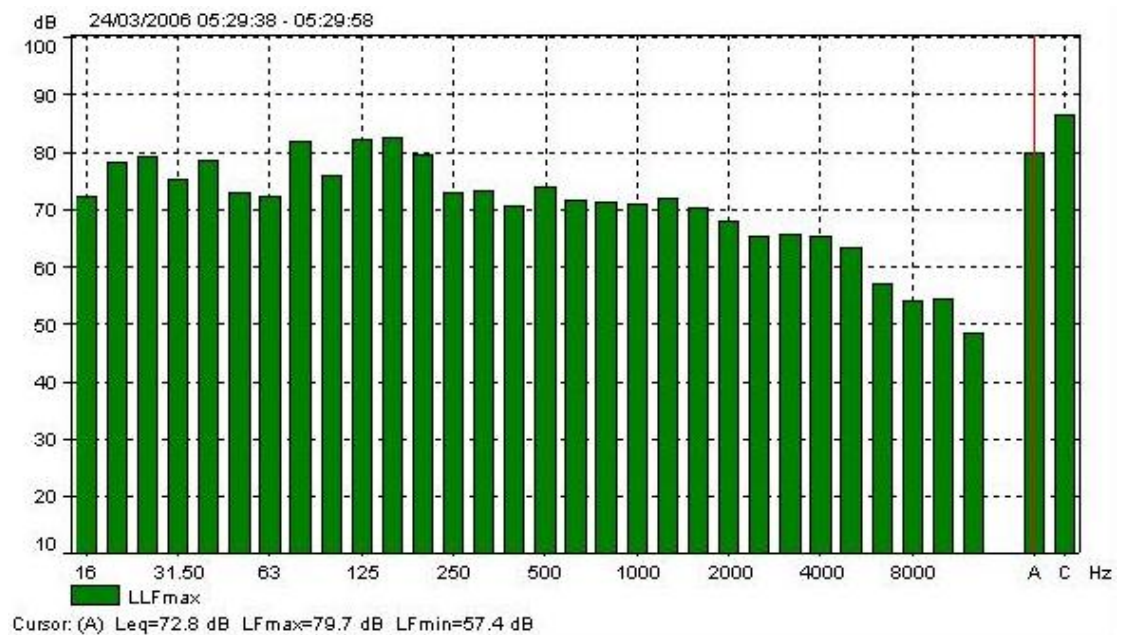


Figure I.12. Moving full roll-cages along the pavement to store A.

The sound pressure levels for the full roll cages moving along the pavement to the store were characterised by peak frequencies in the lower range.

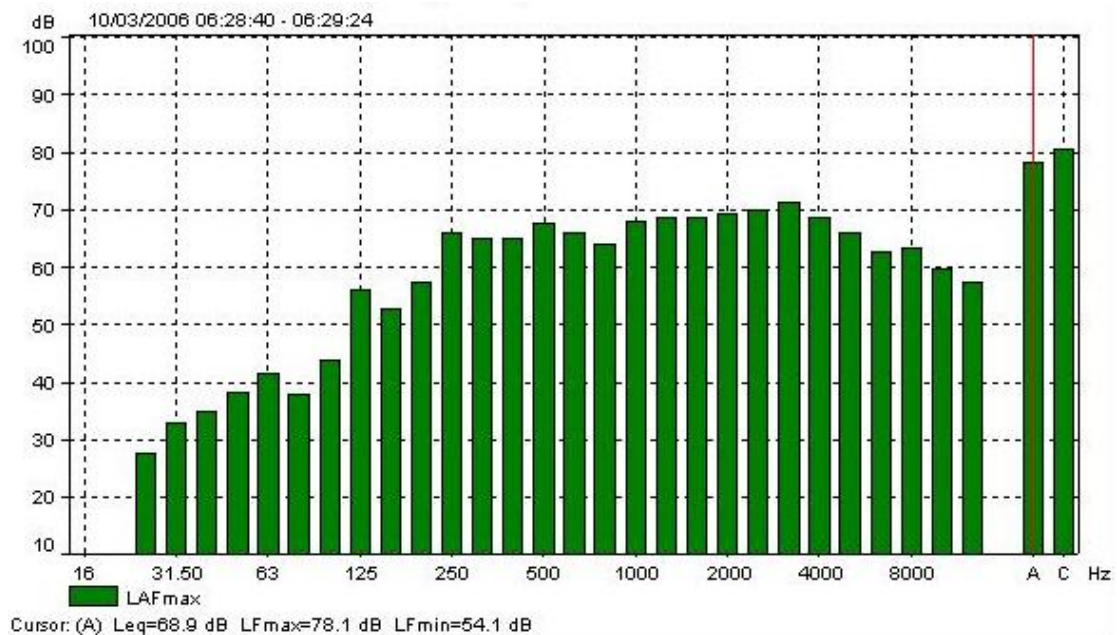


Figure I.13. Movement of empty cages from store C to the HGV

The handling of the empty roll cages along the pavement towards the HGV was characterised by a concentration of frequencies at the higher levels.

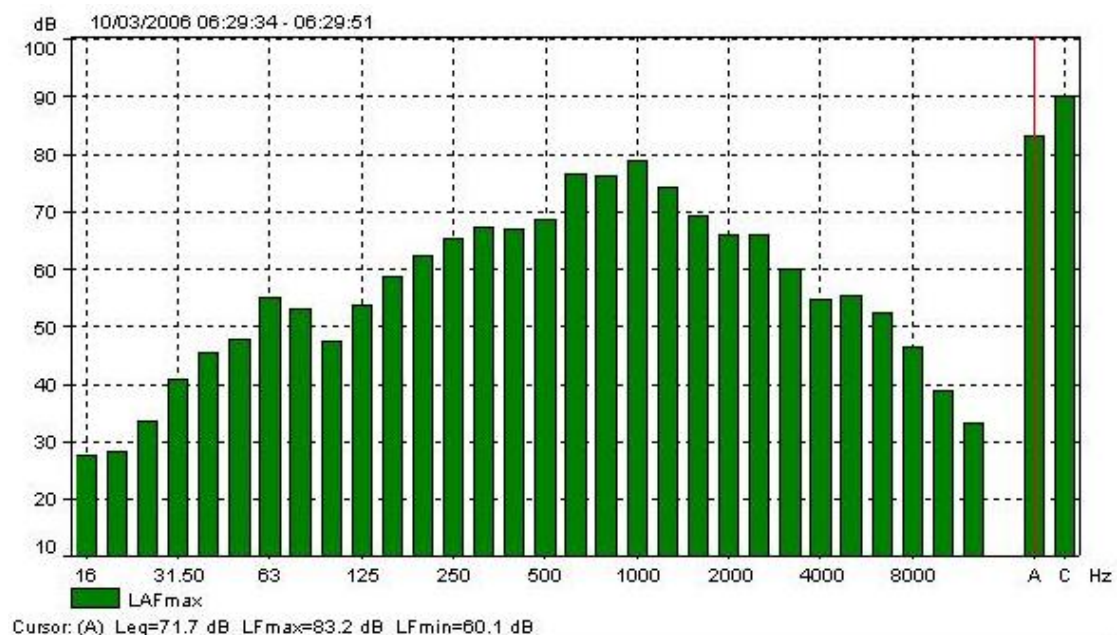


Figure I.14. Loading of empty roll-cage from roadway onto tail-lift at store C.

Peaks were concentrated at 1,000 Hz and 1,600 Hz when the empty roll cages were being loaded onto the tail lift. The pure tone at 1,000 Hz can be clearly seen.

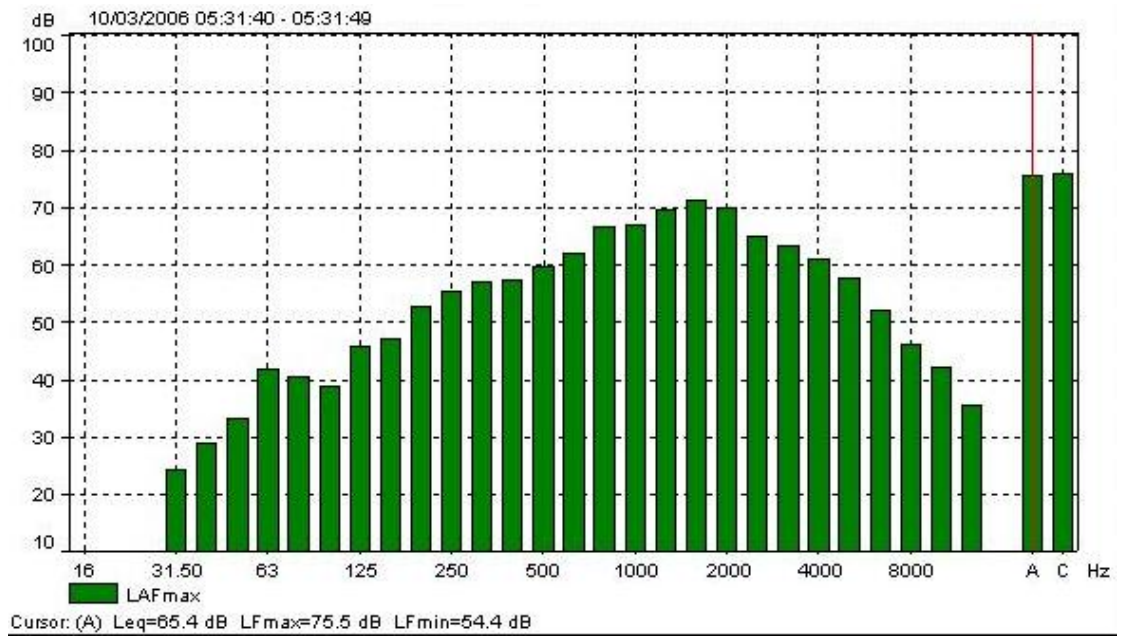


Figure I.15. Manipulation of empty cages from tail-lift into HGV trailer at store B.

A concentration of sound levels between 1,000 Hz and 2,000 Hz was evident.

Appendix II – Acoustic coating (Chapter 4)

II.0. Falling weight tube tests

Tests were carried out on five different coated panels in Batch A (10 X 10cm) and on five different coated panels in Batch B (10 X 15cm). The tests involved dropping the weight repeatedly (X10) from 62cm down the tube into the fixed coated panels and taking measurements in LAF_{max} . The log average sound recorded for 10 drops on the each of the coated samples was compared with the sound from an uncoated blank panel and the reductions achieved were calculated. One of the five samples tested was a proprietary coating obtained from KCN in the Netherlands.

A worked example is shown below Tables II.1. The results of the other tests are recorded in the laboratory log book.

Table II.1. Results for a worked sample calculation for Sample 3, Batch A.

Batch	A
Coated Sample	3 A Front side
Date	02 August 2006
Sound	LAF_{max} (dBA)
Uncoated panel	93.3
Drop 1	89.3
Drop 2	89.8
Drop 3	88.9
Drop 4	89.4
Drop 5	85.8
Drop 6	86.8
Drop 7	91.2
Drop 8	87.4
Drop 9	87.7
Drop 10	89.1
Log Average	88.8
Reduction	4.5

The test results showed that –

1. Significant reductions were achieved by the application of surface coatings, ranging from 2.2 dB(A) to 5.5 dB(A) when compared with an uncoated panel.
2. In Batch A sample 1A (coated side) had the best results with a reduction of peak sound of 5.5 dB(A). The second best was Sample 3A (coated side) with a reduction of peak sound of 4.5 dB(A).
3. In Batch B sample 1B (coated side) showed the best results with an average reduction of peak sound of 4.7 dB(A).
4. The level of reduction achieved by the best samples regarded as making a noticeable difference to the perceived sound (Briel and Kjaer, 2006, pdf).

Abrasion wear tests were carried out by CREST on the five formulations including the KCN coating. The results are shown below in Table II.2.

Table II.2. Wear tests on the 5 coatings including KCN.

Sample	1	2	3	4	5(KCN)
<u>Thickness (µm)</u>					
Batch A. Panels (4X4)	1500	624	634	700	1251
Batch B. Panels (6X6)	896	321	319	524	629
Abrasion Wear (cycles per mil, W)	274.7	417.7	171.5	245.1	152.4

From the Table II.2 above it can be seen that the commercially available KCN (sample 5) had the best resistance to abrasion. However the KCN sample provided the least noise attenuation when compared to the other samples. It is clear that the harder the coating the less acoustic attenuation the material can provide. The noise reductions achieved are compared in Tables II.3 and II.4 below.

Table II.3. Falling weight tube acoustic results compared

Batch A (4"x 4"), Front impact			
Sample	Date	Average (dB)	Reduction (dB)
<i>Uncoated</i>	<i>03-Aug-06</i>	<i>93.3</i>	<i>-</i>
1A	02-Aug-06	87.8	5.5
2A	02-Aug-06	90.2	3.1
3A	02-Aug-06	88.8	4.5
4A	02-Aug-06	91.1	2.2
5A	03-Aug-06	91.0	2.3
6A	04-Aug-06	89.7	3.6

Table II.4. Falling weight tube results for Batch B

Batch B (6"x 4"), Front impact			
Sample	Date	Average (dB)	Reduction (dB)
<i>Uncoated</i>	<i>04-Aug-06</i>	<i>93.1</i>	<i>-</i>
1B	03-Aug-06	88.4	4.7
2B	03-Aug-06	91.3	1.8
3B	03-Aug-06	91.2	1.9
4B	03-Aug-06	89.9	3.2
5B	03-Aug-06	91.3	1.8

II.1. Falling weight tests (large scale)

The materials tested were those typically used on the floors of the trailer and tail gate platform, namely aluminium plate and mild steel plate.

Table II.5. Falling weight test carried out on aluminium (Al) and mild steel (MS) panels in the laboratory

	Noise from Impact [LAF_{max} (dBA)]			
Substrate Material	MS	MS	Al	Al
Test Date	23 Nov '06	06 Dec '06	23 Nov '06	06 Dec '06
Front (F) / Rear (R)	F	F	F	F
Coated (C) Uncoated (U)	U	C	U	C
Background	55.1	54.8	55.2	54.3
Logarithmic Average [LAF_{max} (dBA)]	100.2	85.6	103.0	88.1
Difference [LAF_{max} (dBA)]	14.6		14.9	

In Table II.5 above; the logarithmic averages of LAF_{max} in dB(A) were obtained by recording the measurements from 10 drops of the falling weight on to the various panels being tested in the laboratory; a complete set of these values can be inspected in the laboratory log book.

II.2. Pendulum tests

The panels tested comprised the following substrates of 1 meter square panels.

Uncoated substrates:

Sample A1: smooth GRP, both sides

Sample A3: Aluminium, (5 fingered) chequer plate, both sides

Sample A4: Mild steel (1.5mm thick), chequer plate, both sides

Coated substrates:

Sample A1: smooth GRP, coated side

Sample A3: aluminium, chequer plate, coated side

Sample A4: mild steel, chequer plate, coated side

Application of damping composites:

Sample B1: “Ygro” Σ -dead Eliminator (damping substrate) applied to smooth sides of aluminium and mild steel panels.

Sample B2: “Ygro” Σ -dead Original (damping substrate) applied to smooth sides of aluminium and mild steel and panels.

The tests were carried out in the Physics Laboratory and the results are recorded in the laboratory log book. A number of sample tests are reported below.

Table II.6. Pendulum test carried out on aluminium (Al), mild steel (MS) and glass reinforced plastic (GRP) panels in the laboratory

	Noise from Impact [LAF_{max} (dBA)]					
Substrate Material	GRP	Al	MS	GRP	Al	MS
Test Date	22 /11/06	22/11/06	23/11/06	6/11/06	6/11/06	6/11/06
Material	A1	A3	A4			
Front (F) / Rear (R)	R	F	F	R	F	F
Coated (C) Uncoated (U)	U	U	U	C	C	C
Background	55.8	56.0	56.1	54.5	54.3	55.5
Logarithmic Average [LAF_{max} (dBA)]	86.8	92.0	87.4	74.7	70.2	72.9

In Table II.6 above; the logarithmic averages of LAF_{max} in dB(A) were obtained by recording the measurements from 10 swings of pendulum into the various panels for testing; the full set of these values can be seen in the laboratory log book.

The following substrates were coated by CREST with an acoustic damping formulation:

1. Mild steel chequered plate
2. Aluminium chequered plate
3. GRP smooth panel

II.3. Acoustic adhesive “Ygro” strips

Two damping materials are tested:

Σ -Dead Eliminator and Σ -Dead Original

Both of these materials were applied to:

- a) mild steel plate (smooth reverse side)
- b) aluminium plate(smooth reverse side)

Table II.7. Pendulum test carried out on aluminium (Al) and mild steel (MS) panels in the laboratory using Σ -Dead eliminator and Σ -Dead original

	Noise from Impact [LAF_{max} (dBA)]			
Substrate Material	MS	MS	Al	Al
Test Date	8 Dec ‘06	11 Dec ‘06	8 Dec ‘06	11 Dec ‘06
Front (F) / Rear (R)	R	R	R	R
eDead Eliminator (E) eDead Original (O)	E	O	E	O
Background	54.7	55.4	54.7	55.7
Logarithmic Average [LAF_{max} (dBA)]	90.4	90.4	88.7	89.7

In Table II.7 above; the logarithmic averages of LAF_{max} in dB(A) were obtained by recording the measurements from 10 swings of the pendulum into the aluminium and mild steel panels with “YGRO” Σ -Dead original and Σ -Dead eliminator commercially available damping materials applied to the substrates in the laboratory; the full set of these values can be inspected in the laboratory log book.

Table II.8. Summary of the laboratory tests carried out for aluminium (Al)

Test	Uncoated (dB)	Al + Attenuative material (dB)	Difference (dB)
Pendulum (Al+coating)	92.0	70.2	21.8
Falling Weight (Al+coating)	103.0	88.1	14.9
Falling Weight (Al+E-Dead Eliminator)	103.0	88.7	14.3
Falling Weight (Al+E-Dead Original)	103.0	89.7	13.3

Table II.9. Summary of the laboratory tests carried out for mild steel (MS)

Test	Uncoated (dB)	MS + Attenuative material (dB)	Difference (dB)
Pendulum (MS+coating)	87.4	72.9	14.5
Falling Weight (MS+coating)	100.2	85.6	14.6
Falling Weight (MS+E-Dead Eliminator)	100.2	90.4	9.8
Falling Weight (MS+E-Dead Original)	100.2	90.4	9.8

Table II.10. Summary of the laboratory tests carried out for glass reinforced plastic (GRP)

Test	Uncoated (dB)	GRP + Attenuative material (dB)	Difference (dB)
Pendulum (GRP+coating)	86.8	74.7	12.1
Falling Weight (GRP+coating)	98.5	91.1	7.4
Falling Weight (GRP+E-Dead Eliminator)	98.5	N/a	N/a
Falling Weight (GRP+E-Dead Original)	98.5	N/a	N/a

II.3.1. Conclusions

Aluminium

- The application of a **coating** reduced the dB by;
 - Pendulum: **21.8 dB Logarithmic Average**
 - Falling weight: **14.9 dB Logarithmic Average**
 and attenuated the higher frequencies
- The application of a **E-dead Eliminator** reduced the dB by;
 - Falling weight: **14.1 dB Logarithmic Average**
 and attenuated the higher frequencies
- The application of a **Σ -dead Original** reduced the dB by;
 - Falling weight: **13.3 dB Logarithmic Average**
 and attenuated the higher frequencies

Mild Steel

1. The application of a **coating** reduced the dB by;
 - a) Pendulum: **14.5 dB Logarithmic Average**
 - b) Falling weight: **14.6 dB Logarithmic Average**and attenuated the higher frequencies

2. The application of a **E-dead Eliminator** reduced the dB by;
 - a) Falling weight: **9.8 dB Logarithmic Average**and attenuated the higher frequencies

3. The application of a **E-dead Original** reduced the dB by;
 - a) Falling weight: **9.8 dB Logarithmic Average**and attenuated the higher frequencies

GRP

1. The application of a **coating** reduced the dB by;
 - a) Pendulum: **12.1 dB Logarithmic Average**
 - b) Falling weight: **7.4 dB Logarithmic Average**and attenuated the higher frequencies

2. It is not appropriate to apply **Σ-dead Eliminator** as this composite is not suitable for application to the floor of the trailer due to its lack of robustness.

The next step was to test the coating on-board a HGV trailer unit by means of the portable pendulum apparatus and the portable falling weight apparatus.

II.3.2. Influence of clamping forces on the excitation and frequencies of the panels.

It was decided to investigate the effects of different clamping loads on the impact noise using the pendulum apparatus. The tests were carried out on 17th June 2008.

The panels under test were sandwiched between a fixed vertical metal frame mounted on the laboratory floor and a demountable frame. This was done by means of four clamps which were bolted through the vertical frame. Spacers were also used between the panel and the demountable frame to ensure an evenly distributed clamping load.

The pendulum weight (0.907 kg) was suspended from both sides at the top of the fixed frame by means of a wire. The suspended weight was designed to strike the panels under test at a distance of 150 mm from the base of the plate.

Before starting the pendulum tests the background noise level was measured for 3 minutes. The weight was then realised at a distance of 150 mm from the front of the panel and caught after each impact for a pause of 5 seconds before being again released.

The procedure was repeated 10 times for each test and the noise levels were recorded in accord with BS 4142.

Three different clamping forces were applied to the three panels under test. The forces were (1) 12 Nm (2) 16 Nm and (3) 20 Nm. The panels comprised (a) an uncoated aluminium panel with a barley seed pattern (b) an uncoated diamond patterned mild steel panel and (b) a coated patterned mild steel panel.

The results were recorded in LAF_{max} and the logarithmic averages for the ten impacts conducted during each test were correlated against the different clamping forces applied to the panels.

It will be seen that the application of increasing torque applied to the clamps had no significant effect on the sound values generated by impacting the panels.

It was also considered useful to investigate whether the application of different torque values affected the frequency characteristics of the panel.

Discussion:

The results of this experiment may be explained by the fact that the panels were of relatively dense metals, of 2 mm for the barley seed aluminium and 3 mm for the mild steel diamond plate. The clamping forces did not put the panels in tension unlike, for example, in the case of a vibrating diaphragm of a musical instrument like a drum.

It can therefore be concluded that relatively thick aluminium or mild steel panels which are firmly secured to the floor of a HGV would not be unduly influenced by the clamping forces applied.

II.4. The test site pendulum tests

Date: 22 January 2007

Present: Hugh Finlay, Roisin Byrne

Table II.11. Pendulum test carried out on glass reinforced plastic (GRP) panels in the test site (22 January 2007)

	Noise from Impact [LAF_{max} (dBA)]					
Position	1	1	2	2	3	3
Coated (C) Uncoated (U)	U	C	U	C	U	C
Logarithmic Average [LAF_{max} (dBA)]	75.1	75.0	75.0	74.1	76.6	74.1

In Table II.11; the logarithmic averages of LAF_{max} in dB(A) were obtained by recording the measurements from 10 swings of the pendulum into the GRP panels at the test site field trials; the full set of these values can be seen in the laboratory log book.

Little or no noise reduction was evident as between striking the coated and uncoated panel with the pendulum weight.

II.5. The test site falling weight tests

Date: 22 January 2007

Present: Hugh Finlay, Roisin Byrne

Table II.12. Falling weight test carried out on aluminium (Al) and mild steel (MS) panels in the test site (22 January 2007)

	Noise from Impact [LAF_{max} (dBA)]							
Substrate Material	Al	Al	Al	Al	Al	Al	MS	MS
Position	1	1	2	2	3	3	N/a	N/a
Coated (C) Uncoated (U)	U	C	U	C	U	C	U	C
Logarithmic Average [LAF_{max} (dBA)]	90.9	84.0	87.4	85.3	92.2	84.9	95.1	86.1

In Table II.12; the logarithmic averages of LAF_{max} in dB(A) were obtained by recording the measurements from 10 drops of the falling weight on to the various aluminium and mild steel panels at the test site field trials; the full set of these values can be seen in the laboratory log book, but have been summarised in Tables 4.7 and 4.8.

II.6. Summary of laboratory test results

II.6.1. Measuring the durability of the coating applied to the panels on the carousel test rig

It was found that the coating was not sufficiently durable in service and showed severe wear after two months in service, for this reason General Paints Ltd. and CREST continued to develop the coating by applying a top protective top coat to the formulation in order to enhance durability.

The revised system comprised of a one pack acrylic primer (25-30 μ m), water based acoustic coating (500 μ m) and a two pack epoxy topcoat (100-130 μ m) as a final protective hard cover for the floor of the HGV trailer and tail-lift platform.

In order to create a non-slip surface, aluminium oxide grit was incorporated into the topcoat. The durability of the revised formulation was tested on the carousel apparatus.

II.6.2. Tests on board the carousel test rig

A special carousel test rig was designed and built in DIT engineering workshop in Bolton St. to help develop a “hush-kit” for application and for retro-fitting to standard steel roll-cages. The carousel could also be adapted to assess the durability of the new acoustic coating.

As described later in Chapter 5 and appendices, the carousel was 2.5m in diameter, comprising a plywood platform mounted on a steel frame and was motorised and controlled hydraulically to simulate the pushing of a roll-cage at walking speed.

The test involved the coating by General Paints Ltd., under controlled conditions, of two 1 meter square aluminium panels. One panel was pre-treated with a primer, the other without because it was believed that the application of a primer would improve durability. The panels were fixed to the rotating carousel platform.

Partly loaded roll-cages were placed on the carousel and held in stationary positions while the platform was allowed to rotate. The surfaces of the panels under test passed underneath the wheels of the roll-cage for a given number of cycles at a controlled speed.

The carousel was set to run for 20,000 cycles. This number of cycles was calculated to equate to the assumption that a typical trailer is loaded and unloaded once a day, with 48 partly-filled roll cages, for five days every week and that the wheels pass back and forth across the same path at the rear of the trailer and tail lift platform. In service the roll-cages that are put back into the trailer after delivery are empty and are therefore much lighter (30 kg) than the partly filled roll-cages exiting the trailer. A partly loaded rollcage, carrying 78 kg., was therefore anchored to the carousel test rig placing a total load of 108 kg on the coated panels under test when the carousel was put in motion.

A schematic diagram of the carousel showing the position of the roll-cage, the wheel tracks and the panels under test is shown in Figure II.1.

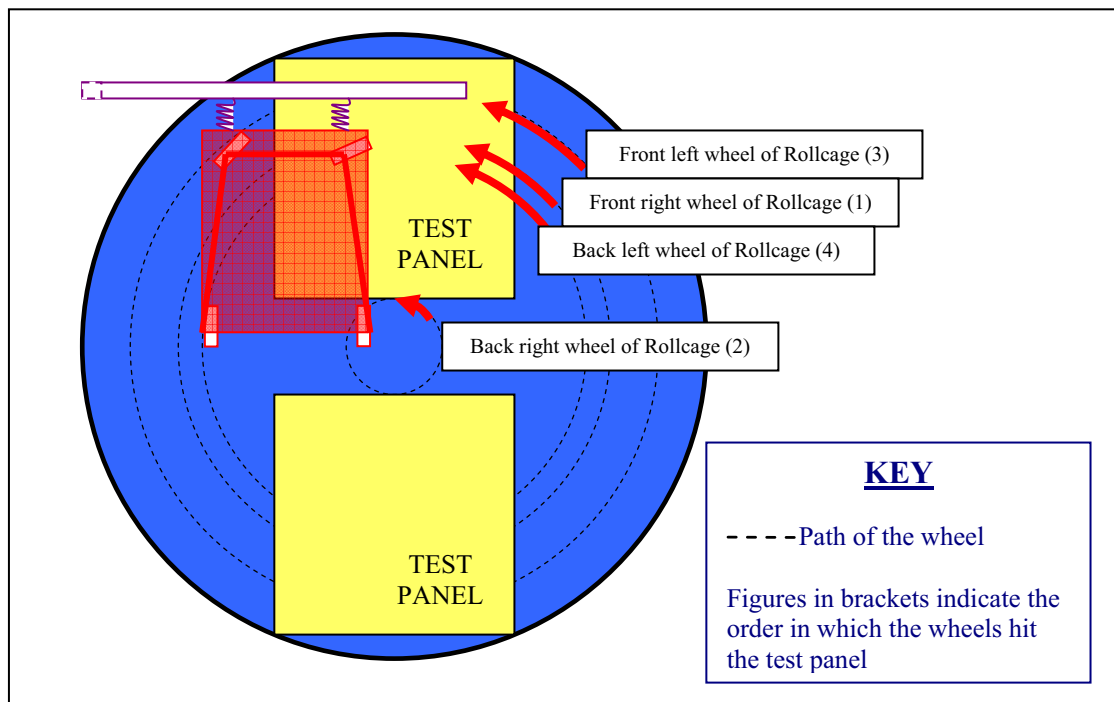


Figure II.1. Schematic showing the different paths of the four wheels of the roll-cage during the durability tests of the coated panels.

The first set of tests required that the partly filled roll-cage be transited across two aluminium coated panels, the first with primer (A), and the second without a primer (B).





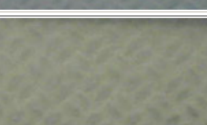

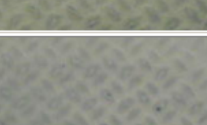
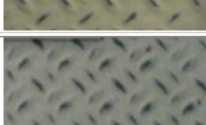
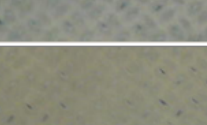
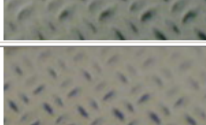

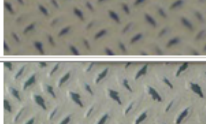
The durability was assessed by recording the loss of thickness occurring after the measured passage of the wheels of a loaded roll-cage over carefully prepared coated panels. Thickness measurements were taken of the most abraded areas of the specimen panels after set numbers of passages. The procedures were as follows -

The two candidate panels “A” and “B” were fixed at opposite ends of the carousel. A standard steel loaded roll-cage was anchored to the test rig support frame and the carousel was allowed to rotate underneath the wheels. The speed of the carousel was set to 3 km/hr. Dirt particles that were embedded in the paint during the manufacturing / application processes were clearly marked. The wear tracks caused by the four wheels of the loaded cage were carefully marked out. Visual records of the wear occurring were taken at intervals of approximately 2,000, 8,000, 13,000, 16,000

and 20,000 rotations. These cycle intervals approximate to different time periods in fleet use as described in Table II.13.

Photographic record was taken of the wear of panels A and B for increasing number of cycles.

Table II.13. Photographs of wear for panels A and B at different numbers of cycles

No. of Cycles	Equivalent Period	Wear on Panel A	Wear on Panel B	Noise Generated [L _{Aeq} (dBA)]
912	13 days			72.0
1,983	1 month			73.1
8,088	3.9 months			71.3
13,002	6.3 months			71.8
15,624	7.5 months			71.0
20,235	9.7 months			70.0

The reduced thicknesses of the abraded areas were measured by means of a dial gauge as shown in Figures II.3 and II.4. This was done by removing the panels from the carousel and placing them onto a steel table. The dial gauge was set to zero on the steel table before the thickness measurements were taken. The areas where the most visible abrasion occurred were identified by visual inspection (and highlighted with green marker) as were the unaffected areas. The reduced thicknesses of the most severely abraded areas were measured and compared with the thicknesses of the least abraded areas. The thickness of the abraded marked areas of the panel was measured with a dial gauge at five different points along the top ridges or “teeth” of the barley

seed patterns. The most abraded areas could be easily seen when the black acoustic layer began to show through the worn yellow top coat. The most heavily abraded areas were the tracks traversed by the rear wheels of the loaded roll-cage, Figure II.1. The loss of coating was measured by comparing the thicknesses of the coating on the marked abraded areas with the thickness of the areas unaffected by the wheels of the roll cage. Five measurements were taken with the dial gauge to calculate the average value. The thickness of the coatings on Panels A and B was also calculated with reference to an uncoated aluminium panel. The dial gauge measurements were checked using an anvil micrometer.

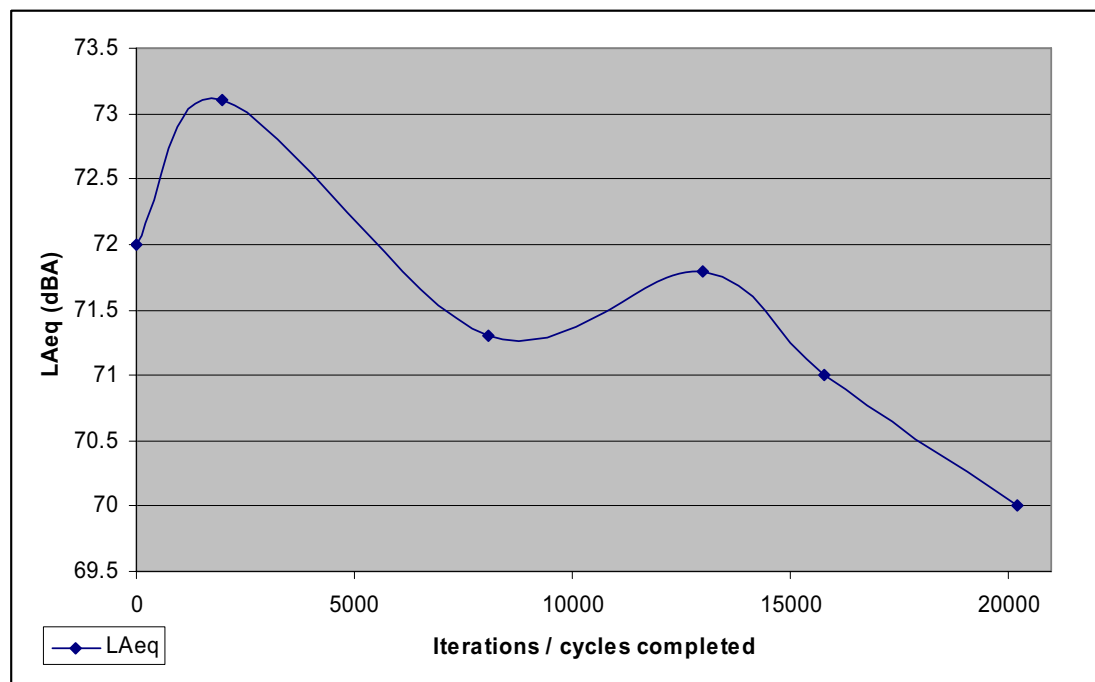


Figure II.2. Graph showing the rate of change of noise generated by a roll cage on a carousel with panels A and B on the rotating platform, as per the values listed in Table II.13.

In relation to Table II.13 and Figure II.2 the values of LAeq for the noise testing on the carousel refers to the average over a 7 minutes time period and also takes into account the noise of the wooden platform of the carousel. It should be noted that for a new panel the noise increased and then after about 2,500 iterations or cycles on the carousel the noise generated reduced; this occurrence was due to the fact that the hard top layer of the coating was being smoothed over by the wheels. After about 13,000 iterations the noise generated reduces more rapidly, this is because the hard top coat has been significantly penetrated one of the panels and the wheels are now running on

the soft acoustic layer located below the hard top coat. This confirms the earlier tests with the tube falling weight test in the laboratory where the commercially available KCN coating had a lower acoustic performance than the coating developed by General Paints.



Figure II.3. Photograph showing a measuring point on an abraded part of panel A.

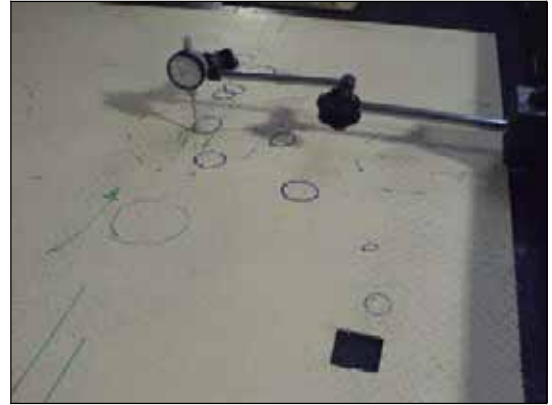


Figure II.4. Photograph of abraded areas marked in green from which thickness measurements were recorded.

II.6.3. Test results and analysis

Four abraded areas of the panel were marked along the paths of the wheels as described in Table II.14 and illustrated in Figure II.1. The abraded areas on Panel A for which thickness measurements were taken are shown in Table II.15.

Table II.14. Abraded areas of panels A selected for the measurements of wear

Location	Description	Notes and Comments
Area 1	Heavily abraded area	Black acoustic layer was clearly visible
Area 2	Mildly abraded area	No wear through the top coat
Area 3	Mildly abraded area	No wear through the top coat
Area 4	Partially abraded area	Black acoustic layer was partially visible

The thicknesses on these abraded areas are recorded in Table II.15. These measurements are the averages of five readings taken from each marked area as described in Figure II.1.

Table II.15. Average depth of wear in four marked areas on panel A following 20,235 cycles

	Thickness (µm)				
Location	Area 1	Area 2	Area 3	Area 4	Average
Depth of wear (µm) after 20,235 cycles	189	67	147	145	137

The uncoated aluminium substrate was measured at 5 points to the tops of the teeth of the barley seed pattern to give an average value of 2476 µm.

The thickness of the unabraded coated Panel A was then measured to the tops of the teeth. This consisted of the aluminium substrate, a primer layer, an acoustic layer and a top coat layer. The average over 5 measured points was 2971 µm. This means that the thickness of the coating applied to Panel A was 495 µm.

Measurements were then taken of four abraded areas after 20,235 cycles to give an average depth of wear compared with the un-abraded areas, of 137 µm as shown in Table II.15. The average thickness of the remaining coating was 358 µm, as described in the student log book.

This exercise was repeated for unabraded areas on Panel B which consisted of only two layers, an acoustic layer and a top coat layer. When measured over 5 points to the top of the peaks an average thickness of 2822 µm which equates to an average thickness of 346 µm of coating applied to Panel B. The thickness of the un-abraded coating on Panel B was 2822 µm and the thickness of the abraded coating was 2608 µm, giving a depth of wear of 214 µm after 20,235 cycles as shown in Table II.16 below.

It must be noted that the coating on Panel A was thicker than that on Panel B due to the inclusion of a layer of primer layer.

Table II.16. Average wear loss after 20,235 cycles on panels A and B

	Unabraded (µm)	Abraded (µm)	Wear Loss (µm)
Panel A	2971	2834	137
Panel B	2822	2608	214

Table II.17. Thickness measurements to the top of the teeth carried out on an uncoated aluminium substrate and panel A in an unabraded state and in an abraded state after 20,235 cycles.

	Thickness (mm)							
	Uncoated Aluminium Panel	Unabraded Panel			Abraded Panel			
		Area 1	Area 2	Area 3	Area 1	Area 2	Area 3	Area 4
Average Thickness (mm)	2.48	2.90	2.97	3.04	2.78	2.90	2.82	2.83
Panel & Coating Thickness (mm)	-	2.97			2.83			
Coating Thickness (mm)	-	0.49			0.35			

In Table II.17; the average thickness of the aluminium panels were obtained by recording the measurements from 5 locations on the panel, these values can be seen in the laboratory log book.

II.6.4. Cross checking of the dial probe with a micrometer

The thickness measurements taken by the dial gauge were compared with a series of measurements at the same locations taken with a micrometer. It was found that the variation was 0.16% for the uncoated panel and 0.79% for panel B. These two procedures gave a satisfactory correlation. For detailed measurements see student log book.

II.6.5. Measuring the thickness of a coated unabraded panel B (without primer)

Table II.18. Thickness levels of abraded and unabraded coating on panel B

	Panel thickness (mm)	
	Unabraded	Abraded
Average Thickness (mm)	2.82	2.61
Average Thickness (µm)	2822	2608
Wear (µm)	214	

In Table II.18; the average thickness of the aluminium panels were obtained by recording the measurements from 5 locations on the panel for abraded and unabraded areas, these values can be seen in the laboratory log book.

II.6.6. Comparison of dial gauge measurements and micrometer measurements using an uncoated aluminium panel using the same test points.

Table II.19. Correlation of dial gauge and micrometer readings to measure thickness

	Panel thickness (mm)	
	Dial Gauge	Micrometer
Average Thickness (mm)	2.48	2.48
Average Thickness (μm)	2476	2480
Percentage error	0.16 %	

In Table II.19; the average thickness of the aluminium panels were obtained by recording the measurements from the 5 locations on the panel using the dial gauge and the same 6 locations with the micrometer, these values can be seen in the laboratory log book.

Table II.20. Results for panel B (back right wheel) comparing measurements from a dial gauge to a micrometer

	Panel thickness (mm)	
	Dial gauge	Micrometer
Average Thickness (mm)	2.61	2.59
Average Thickness (μm)	2608	2587.5
Percentage error	0.79 %	

In Table II.20; the average thickness of the aluminium panels were obtained by recording the measurements from 5 locations on the panel using a dial gauge and from the 4 locations using the micrometer, these values can be seen in the laboratory log book.

Appendix III – Hush kit (Chapter 5)

III.0. Specifications of the carousel test rig

Due to space constraints in the workshop, the diameter of the platform was restricted to 2.5 m. A larger diameter would have allowed for less tighter tracks for the inner castor wheels.

The rotational speed settings were measured and stabilised before sound recordings were taken.

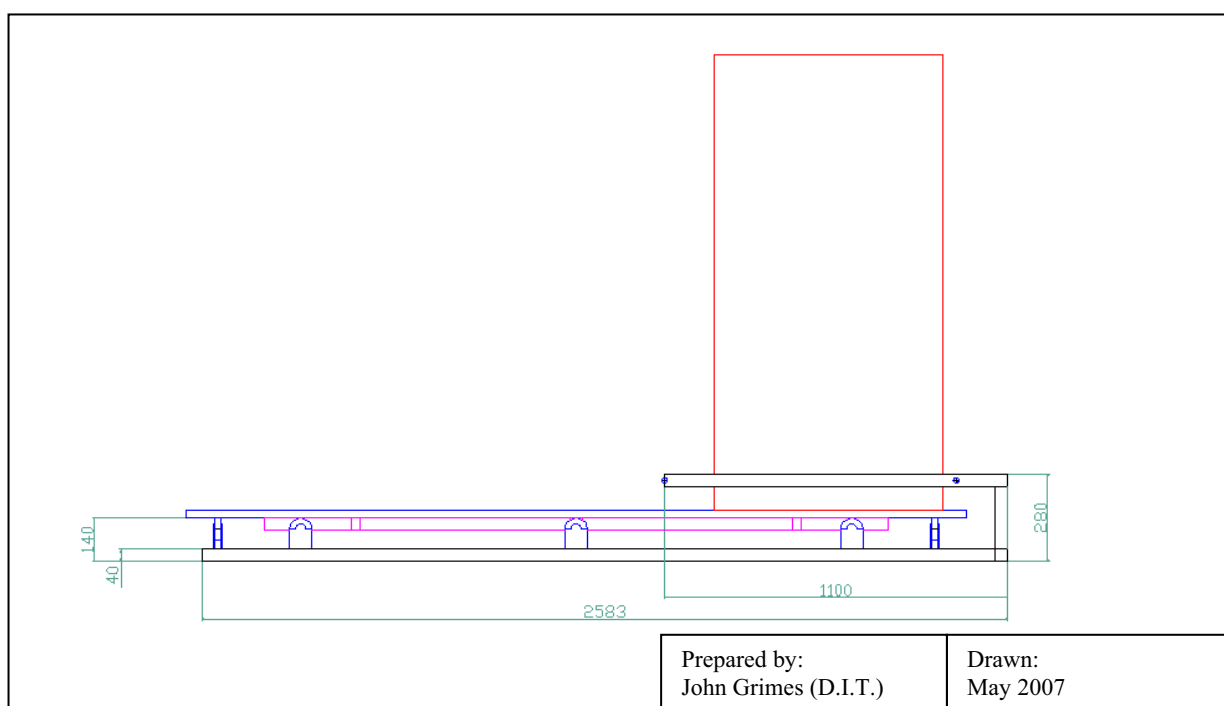


Figure III.1. Elevation view of carousel test rig

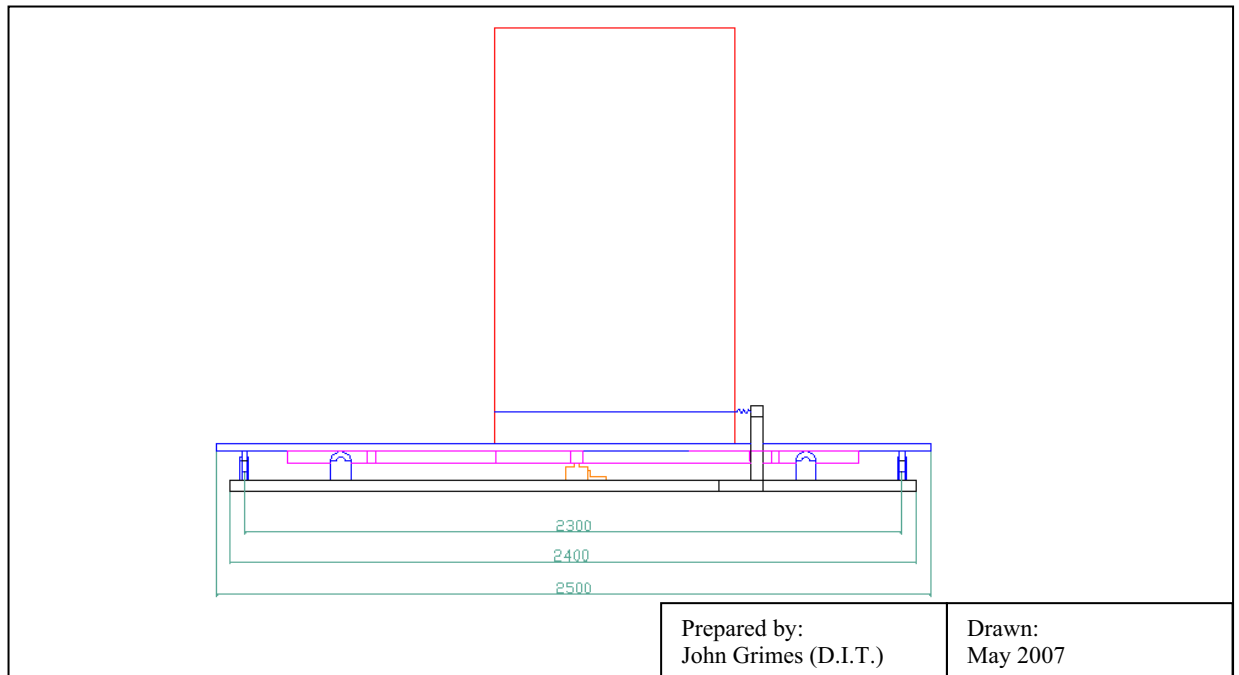


Figure III.2. End view of carousel test rig

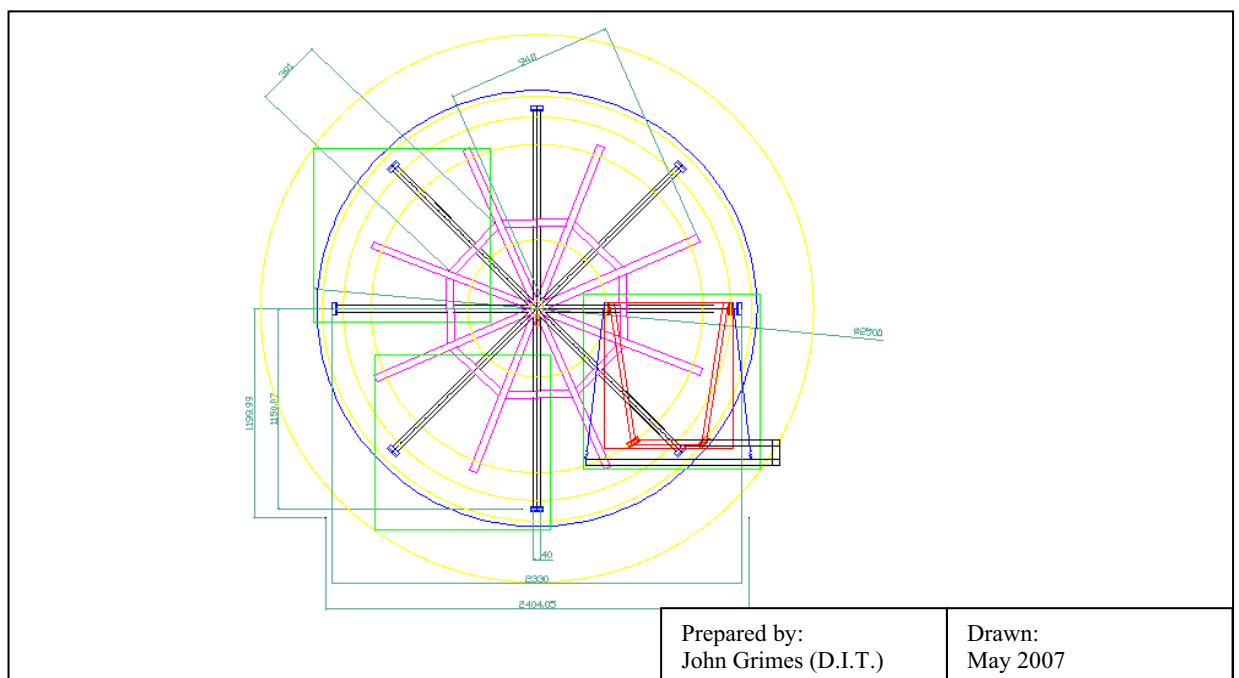


Figure III.3. Plan view of carousel test rig

III.1. Modifications to castors and wheels

Different modifications were made to the castors and wheels and the noise recorded for a period of 5 minutes. The reductions achieved were compared with a non modified castor unit as shown in Table III.1.

Table III.1. Noise from selected commercially available castor units and modifications to standard castor compared.

Modifications to Castor Unit and Wheels	Noise Level (dB(A))	
	Modified	Reduction
Standard Hartwall rear (Ø125mm) wheel (61.7 dB(A)) on a fixed castor angled for the rotating platform		
10mm thick rubber annulus Ø90mm as used above	64.4	-2.7
2 grooves cut into the rolling surface	60.8	0.9
o-rings fitted into the 2 grooves	57.0	4.7
Commercially available wheel & castor units (Ø125mm), compared with a standard rear wheel (61.7 dB(A))		
Orange rubber tyre wheel with brass coloured swivel castor	63.3	-1.6
Grey rubber wheel with brass coloured swivel castor	61.8	-0.1
Blue rubber wheel & "silent" plastic castor	59.0	2.7
Grey rubber wheel with brass coloured swivel castor c/w 3mm rubber membrane on top of the castor	62.4	-0.7
Orange rubber tyre wheel with brass coloured swivel castor c/w 3mm rubber membrane on top of the castor	63.1	-1.4

III.2. Dropping of the floor onto the A-frame of the cage

The sound recordings made from the repeated dropping of the floor of the cage on the A frame are shown in Table III.2 and III.3. The test was carried by comparing an unmodified cage with a modified cage.

Date: 11 August '07

Start time: 11:34:59

Duration: 00:02:16

Table III.2. Dropping of the floor on to the A-frame of an unmodified cage

Impact No.	L_{eq}	Time of peak event
1	91.8 dB	11:35:38
2	91.2 dB	11:35:49
3	90.7 dB	11:35:59
4	89.2 dB	11:36:07
5	91.6 dB	11:36:16
6	92.1 dB	11:36:24
7	91.0 dB	11:36:32
8	91.9 dB	11:36:40

9	92.2 dB	11:36:48
10	91.8 dB	11:36:55
11	91.3 dB	11:37:02
12	92.3 dB	11:37:09
Logarithmic Average	91.5 dB	

Date: 11 August '07

Start time: 11:24:57

Duration: 00:03:33

Table III.3. Dropping of the floor on to the A-frame of a modified cage

Impact No.	L_{eq}	Time of peak event
1	82.2 dB	11:26:54
2	83.2 dB	11:27:00
3	83.6 dB	11:27:07
4	83.5 dB	11:27:14
5	81.4 dB	11:27:20
6	82.7 dB	11:27:27
7	82.3 dB	11:27:35
8	83.1 dB	11:27:41
9	83.0 dB	11:27:55
10	81.1 dB	11:28:01
11	82.6 dB	11:28:08
Logarithmic Average	82.7 dB	

III.3. Folding of the side of the cage across the castor knuckle

The side of the cage was repeatedly folded across the castor knuckle and sound measurements taken as shown below in Tables III.4, III.5 and III.6.

Unmodified rollcage

Date: 12 August '07

Start time: 16:13:40

Duration: 00:02:09

Table III.4. Folding of the side of an unmodified rollcage

Impact No.	L_{eq}	Time of peak event
1	84.4 dB	16:14:07
2	82.4 dB	16:14:19
3	83.7 dB	16:14:26
4	83.1 dB	16:14:33
5	83.4 dB	16:14:40
6	83.4 dB	16:14:47
7	82.9 dB	16:14:54
8	84.2 dB	16:15:01
9	82.6 dB	16:15:09
10	84.0 dB	16:15:16
11	84.2 dB	16:15:23
12	84.2 dB	16:15:31
13	82.2 dB	16:15:39
Logarithmic Average	83.5 dB	

Unmodified rollcage

Date: 12 August '07

Start time: 11:43:06

Duration: 00:02:30

Table III.5. Folding of the side on an unmodified rollcage

Impact No.	L_{eq}	Time of peak event
1	77.7 dB	11:44:00
2	79.3 dB	11:44:08
3	80.1 dB	11:44:16
4	83.5 dB	11:44:23
5	80.6 dB	11:44:30
6	78.0 dB	11:44:36
7	82.7 dB	11:44:44
8	83.8 dB	11:44:51
9	79.3 dB	11:44:58
10	78.9 dB	11:45:06
11	81.0 dB	11:45:13
12	83.8 dB	11:45:20
13	82.6 dB	11:45:28
Logarithmic Average	81.4 dB	

Modified rollcage

Date: 12 August '07

Start time: 15:12:00

Duration: 00:02:47

Table III.6. Folding of the side of a modified rollcage

Impact No.	L_{eq}	Time of peak event
1	75.7 dB	15:12:59
2	70.7 dB	15:13:08
3	74.3 dB	15:13:16
4	74.3 dB	15:13:23
5	75.7 dB	15:13:30
6	72.7 dB	15:13:37
7	68.8 dB	15:13:45
8	71.7 dB	15:13:53
9	73.8 dB	15:14:01
10	74.1 dB	15:14:08
11	75.6 dB	15:14:16
Logarithmic Average	73.8 dB	

A reduction of 7.7 dB was achieved by the application of the hush kit.

III.4. Measuring the effect of modifications to an empty roll-cage when struck repeatedly against a wall

The impact noise from repeatedly colliding an unmodified empty roll-cage with a modified cage was compared as recorded in Tables III.7 and III.8.

Unmodified roll-cage

Date: 17 August '07

Start time: 15:25:08

Duration: 00:01:33

Table III.7. Impacting of an empty unmodified rollcage against a wall at walking speed

Impact No.	L_{eq}	Time of peak event
1	87.5 dB	15:25:15
2	86.2 dB	15:25:27
3	84.7 dB	15:25:39
4	89.8 dB	15:25:49
5	90.1 dB	15:25:59
6	88.3 dB	15:26:09
Logarithmic Average	88.2 dB	

Modified rollcage

Date: 17 August '07

Start time: 15:28:31

Duration: 00:01:51

Table III.8. Impacting of an empty modified rollcage against a wall at walking speed

Impact No.	L_{eq}	Time of peak event
1	75.8 dB	15:29:00
2	80.4 dB	15:29:11
3	78.2 dB	15:29:20
4	81.2 dB	15:29:31
5	78.8 dB	15:29:41
6	79.9 dB	15:29:49
7	79.0 dB	15:29:59
8	82.2 dB	15:30:10
Logarithmic Average	79.8 dB	

A reduction of 8.4 dB was recorded by the application of the hush kit.

The frequency spectra from the wall tests are shown in Figure III.4.

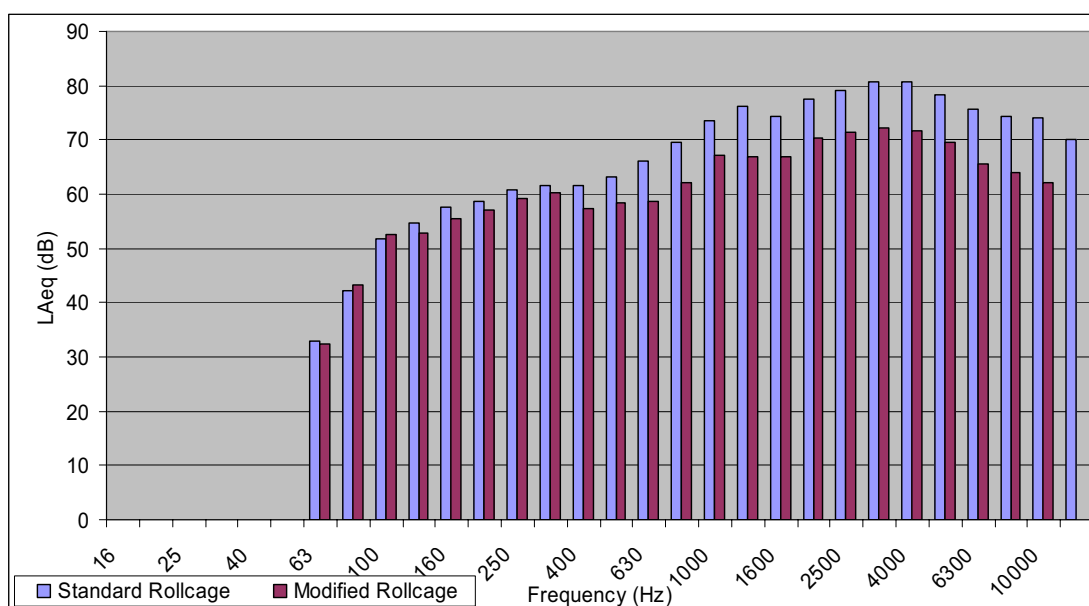


Figure III.4 Frequency spectra showing the effect of hush-kit modifications to an empty cage when struck against a wall (without o-rings).

III.5. Impacting a loaded roll-cage against a wall

Unmodified rollcage

Date: 17 August '07

Start time: 15:38:14

Duration: 00:02:43

Table III.9. Impacting of a loaded unmodified rollcage against a wall

Impact No.	L _{eq}	Time of peak event
1	85.5 dB	15:38:43
2	84.2 dB	15:38:52
3	85.0 dB	15:39:10
4	84.5 dB	15:39:19
5	88.7 dB	15:39:29
6	83.0 dB	15:39:40
7	87.7 dB	15:39:53
8	85.5 dB	15:40:09
Logarithmic Average	85.9 dB	

Modified rollcage

Date: 17 August '07

Start time: 15:50:08

Duration: 00:01:41

Table III.10. Effect of modifying a loaded roll-cage when collided against a wall

Impact No.	L _{eq}	Time of peak event
1	71.3 dB	15:50:15
2	75.0 dB	15:50:26
3	76.2 dB	15:50:36
4	77.5 dB	15:50:46
5	75.2 dB	15:50:56
6	78.0 dB	15:51:12
7	76.1 dB	15:51:22
8	79.1 dB	15:51:32
9	78.3 dB	15:51:40
Logarithmic Average	76.8 dB	

A reduction of 9.1 dB was achieved by application of the hush kit.

The frequency spectra for these events are compared in Figure III.5.

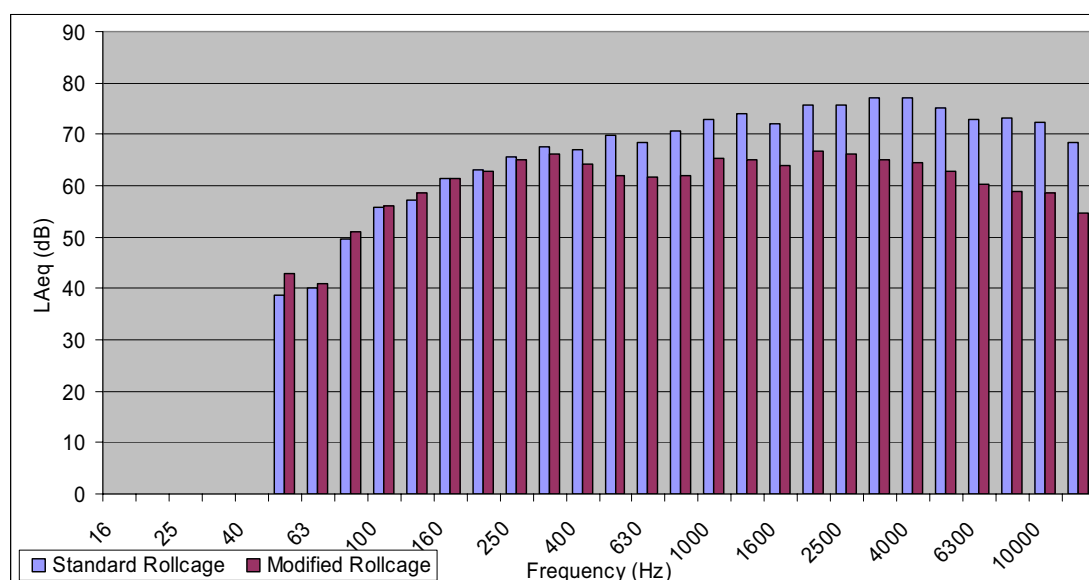














Figure III.5. Frequency spectra showing the effect of hush-kit modifications to a loaded cage when repeatedly struck against a wall.

III.6. Description of hush kit

III.6.1. Components of the hush kit

The components and materials of the hush-kit and the method of application are described and illustrated in Figure III.6

Affected component / procedure	Material	Description & Dimension [LxWxH] (mm)	Quantity per roll cage	Method of fitting	Manufacture (M) & fitting (F) time	Illustration
Front and rear edge of floor panel	Adhesive backed rubber strips	560mm x 20mm x 3mm	2 pieces	Measure and cut to length. Remove adhesive backing & stick to surface		
Top surface of A-Frame	Adhesive backed rubber strips	560mm x 10mm x 3mm	2 pieces	Measure and cut to length. Remove adhesive backing & stick to surface		
Folding floor lattice (non-hinge side)	Rubber hose	Internal Ø4mm (external Ø10mm) x 80mm	4 pieces	Measure and cut to length. Split along one side with a sharp blade	M: 1 min 02 sec F: 1 min 03 sec	
Uprights of lattice frame (4 bottom corners & 6 uprights)	Rubber hose	Internal Ø19mm (external Ø30mm)	4 x 20mm 6 x 50mm	Measure and cut to length. Split along one side with a sharp blade	M: 6 min 27 sec	
Bolt holding front castors to roll cage	Plastic sheet fitted with double sided tape or adhesive	80mm x 50mm x 3mm. Can be manufactured as one piece, then cut in half. A 30mm hole is cut in the centre, opposite sides are then chamfered up to the hole	2 pieces	Apply using adhesive or using double sided sticky tape.	F: 0 min 44 sec (including point 6 below)	

Vertical surfaces facing A frame	Adhesive backed rubber strips	50mm x 40 mm x 3mm	4 pieces	Measure and cut to length. Remove adhesive backing & stick to surface	See above	
Replace straps	Plastic clasps	Replace the metal clasps with plastic alternatives	2 pieces			
Plastic catch for securing hinged floor in upright position	Rubber hose	Internal Ø5mm (external Ø7mm) x 80mm	2 pieces	Measure and cut to length. Split along one side with a sharp blade		
Inside surface of lattice frame for when the floor is moved into upright position	Adhesive backed rubber strips	30mm x 10mm x 3mm	2 pieces	Measure and cut to length. Remove adhesive backing & stick to surface		
Front Swivel Castors	Rubber sheet	Ø80 with a hole Ø 15mm x 3mm.	2 pieces	The rubber ring is fitted between the top of the castor & the base of the roll cage.	M: 1 min 40 sec F: 3 min 06 sec	
Wheels	Urethane o-rings	Ø3mm. Two 2.5mm grooves are cut into each wheel using a lathe	4 Ø125mm 4 Ø100mm	The O-rings are pushed into the grooves & held in place with adhesive.		
Back hinges of lattice	Nylon washers or nylon sheet	M12 (1 – 3mm thick)	2 pieces	A-frame is dislodged from the side, the rear hinge is pulled upwards, and the washer is put into place on the rod pointing upwards. The process is then repeated in reverse to reassemble	M: 0 min 30 sec (est) F: 2 min 40 sec	


				the roll cage.		
Name plate on lattice	Adhesive backed rubber sheet	Visco-elastic sheet 80mm x 40mm x 2mm	1 piece	Adhesive strip is exposed & fitted to the back of the plate in the centre.	M: 0min 15 sec (est) F: 0min 15 sec (est)	

Figure III.6. Datasheet of the components required for the application a hush kit

Total Time for manufacture of hush kit: 9 min 45 sec.

Total Time for fitting of hush kit: 7 min 47 sec.

III.6.2 Explanatory notes

- Above dimensions are approximate and are intended to be used as a guide.
- The estimated noise reductions are based on tests carried out in laboratory conditions on standard modified and unmodified roll cages. These values are based on average results. Testing was carried out in accordance with BS 4142:1997.
- Recommended adhesives are Araldite Rapid or Henkel Loctite Superglue, based on comparative evaluation
- The tools used in the above were simple templates, craft knives and pliers. To reduce time, a hose cutter and band saw should be used.
- The above times do not include time for mixing, application and curing of the adhesives.
- Application of the hush kit is a one person operation.
- Any modifications made to the roll cage are removable and do not involve any operations such as drilling, cutting or welding; warranties to the cage should not be affected.
- Costs were calculated for both the manufacture and application of the hush kit. Significant reductions may be possible by bulk purchasing of pre-measured materials and components.
- Labour costs were calculated (Citizensinformation.ie, 2007).

III.6.3. Application of hush kit to the roll cage

1. Cleaning of all affected surfaces.
2. Layout pre-fabricated hush kit ready for fitting.
3. Removal of wheels & castors.
4. Replace wheels with “o-ring fitted wheels”.
5. Insert rubber washer between castor & frame.
6. Attach the wheels & castors back onto roll cage.
7. Fix machined & chamfered plastic slider plate around the knuckle bolt head for the front castors.
8. Glue rubber strips to the inside of the “A-frame” adjacent to the castor bolt heads.
9. Fasten rubber strips along the top surface of the A-frame.
10. Affix rubber strips to the front & rear edges of the hinged floor.
11. Push 4 pieces of rubber hose onto the non-hinged side of the lower rung of the lattice frame.
12. Fix 4 pieces of rubber hose (20mm long pieces) to the bottom of each corner of the lattice frame, then fix 6 pieces of rubber hose (50mm long) to the appropriate locations on the lattice frame.
13. Stick 2 rubber pads to insides of hinged lattice frame. These should line up with the floor when folded into an upright position.
14. On the plastic strap used to hold the floor upright; plastic hose should be fitted along the lattice rods.
15. Remove metal clasps from the straps; these to be replaced with plastic clasps.
16. Apply vibration damping strip (E-dead eliminator) to the back of the name / ID plate attached to the side lattice.

III.7. Selection of rubbers and damping materials

Commercially available rubbers and materials were selected using an online catalogue from Radionics (2007). The rubber materials selected are described in Figure III.6.

III.8. Adhesives

A simple test carried out on six different adhesives and on double sided tape to investigate the best method of attaching hush kits components to the metal roll-cage. Each of the adhesives was tested by placing a small amount on one side of the rubber fittings. Following cleaning and application each of the adhesive samples was left to cure for 24hrs. The results are shown in Table III.11.

Table III.11. Selection of adhesives

Adhesive used	“Adhesive Power” with preparation to rollcage	“Adhesive Power” without preparation to rollcage	Notes and Comments
Loctite Henkel: Superglue Liquid	Excellent	Excellent	Easy to use and readily available
Loctite Henkel: Superglue Gel	Excellent / Good	Good	Easy to use
Bond Lock: B406	Good	Good	Easy to use
Evo Stik: Serious Glue	Poor	Poor	Readily available, the rubber needed support to help it set, the other adhesives didn’t require this
Araldite: Rapid	Excellent	Excellent	Labour intensive as it is a two part resin and requires mixing prior to use
Araldite: 2014	Good	Poor	Labour intensive as it is a two part resin and requires mixing prior to use

The most suitable adhesive was “superglue”. Double sided adhesive tape was also found to be effective.

III.9. Weights used during testing

The loads applied to the roll-cages and swinging arm apparatus are described below.

Table III.12. Weights applied to cages and arm apparatus.

Item	Weight
Yellow Motor (x2)	16 kg each
Silver Motor	7 kg
Green Motor	18 kg
Oil Drum	21 kg
Empty Rollcage	30 kg
Castor and Wheel Test Arm Apparatus	6 kg